Hawaii Model Energy Code Application Manual

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DISCLAIMER

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APPLICATION MANUAL

MESSAGE FROM THE DIRECTOR

The proposed Model Energy Code, developed by the Department of Business, Economic Development & Tourism (DBEDT), has the potential to save a total of 4.1 million barrels of oil and $241 million in utility costs in 20 years. This is equivalent to about 24 billion kilowatt hours of electricity, enough to power 16,000 homes for 20 years. The adopted code would help clean our air by reducing fossil-fuel burning and provide economic benefits by yielding an average annual rate of return of over 25 percent.

The code is largely modeled after the requirements of ASHRAE 90.1 affecting commercial establishments. Adopting these standards for commercial buildings will bring the state into compliance with the National Energy Policy Act of 1992 which requires that the state certify that it meets or exceeds the ASHRAE code by October 24, 1994. County adoption of the code will also bring the counties in compliance with Act 168, which became law in June 1994 and which requires the counties to adopt an energy code at least as stringent as ASHRAE 90.1 by October 24, 1994. DBEDT is working with the counties to urge the adoption of these or similar provisions.

The Application Manual for the Model Energy Code was developed as a tool for the practitioner. The manual not only explains the requirements of the code, but also contains data and information to assist the design professional in performing the necessary calculations to demonstrate that the building meets the requirements. In many cases, the manual also explains the intent underlying the requirements and reviews the related principles of effective energy conservation design.

This manual is intended to be a supplement to the code, not a replacement.

It is supported by two computer programs written to operate on an IBM-PC or compatible computer. The Lighting Standard program is used to assist in calculating the interior lighting power allowance and lighting control requirements. The Envelope 1 program is used to assist with the building envelope calculations. Both programs produce reports that may be submitted with building permit applications to demonstrate compliance with the code.

Jeanne K Schultz

1. Overview

Preface

Purpose of this Manual

The purpose of this manual is to provide detailed information to architects, engineers, builders and contractors to assist them in complying with the Hawaii Model Energy Code. The manual not only explains the requirements of the code, but also contains data and information required to perform the necessary calculations and to demonstrate that the building meets the requirements. In many cases, the manual also explains the intent underlying the requirements and reviews the related principles of effective energy conserving design.

This manual is intended to be a supplement to the code, not a replacement.

The manual is supported by two computer programs written to operate on an IBM-PC or compatible machine. The LTGSTD program is provided to assist in calculating the interior lighting power allowance and lighting control requirements. The ENV1 program is provided to assist with the building envelope calculations. Both programs produce reports that may be submitted with building permit applications to demonstrate compliance with the code.

Purpose and Intent of the Code

The underlying intent of the Hawaii Model Energy Code is to save energy in buildings. The Hawaiian islands are highly dependent on imported oil at prices and supplies that have proved to be unstable and dependent on world events that can not be controlled by the residents. Since increases in oil prices can quickly and dramatically impact the Hawaiian economy, it is sound public policy to encourage the design of the most efficient buildings possible. The code stops short of requiring the most efficient design possible, but it does require a minimum level of energy efficiency that is easily cost effective in all sectors of the economy. The designer should consider the requirements as a starting point and is encouraged to seek designs which exceed the minimum requirements in energy efficiency and conservation.

Protection of the environment is another important reason for reducing energy consumption. The code is extremely broad in scope, encompassing almost all new construction, including low-rise residential.

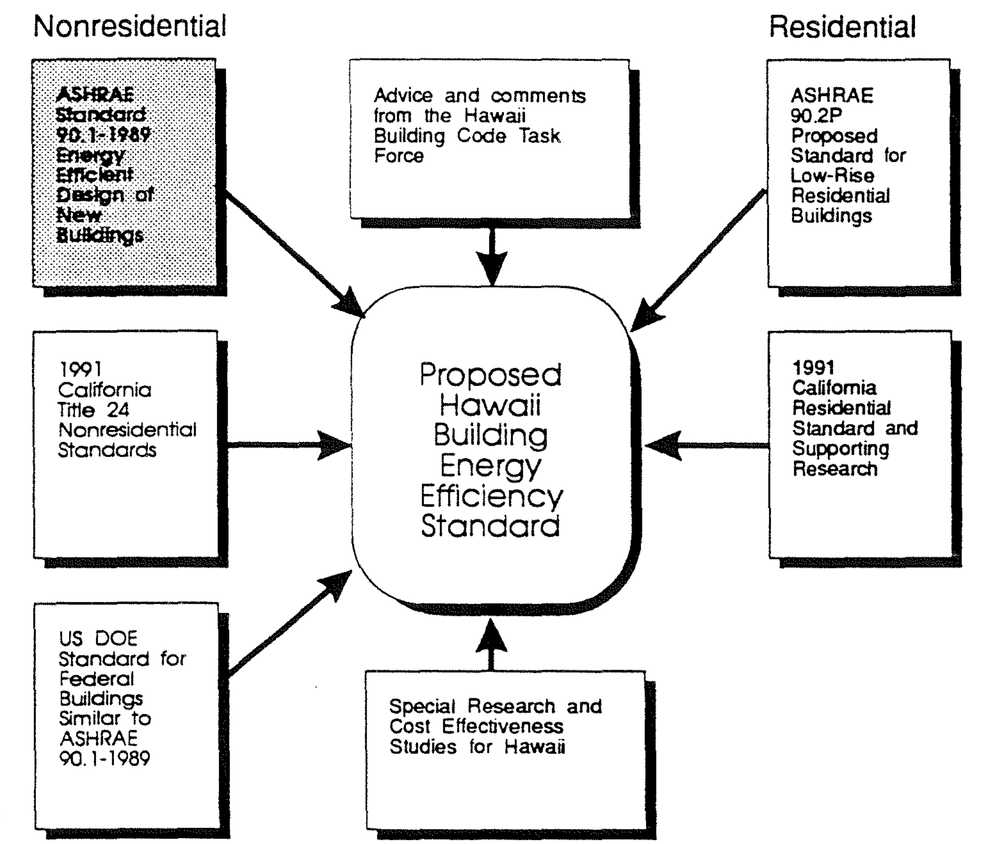
The code includes a set of requirements for the energy-efficient design of buildings and building systems. These requirements assure the application of cost-effective design practices and technologies which minimize energy consumption without sacrificing either the comfort or productivity of the occupants.

Background and History

In 1979 Honolulu adopted a building energy efficiency standard which based on ASHRAE Standard 90-75. The Honolulu code was later adopted by Hawaii, Maui and Kauai. With these adoptions, the State of Hawaii joined most of the rest of United States in having a building energy efficiency standard based on Standard ASHRAE 90-75.

The Hawaii Model Energy Code has been developed over a two year period and has benefited from continued input from the Building Code Task Force, a group that includes engineers and architects practicing on the islands,

Figure 1-A Factors influencing the Hawaii Model Energy Code



building officials, representatives of professional groups and building owners and managers.

Relationship to ASHRAE Standard 90.1-1989

The Hawaii Model Energy Code is adapted from *ASHRAE 90.1-1989 Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings.* ASHRAE 90.1 is a consensus standard that was developed over an approximate 5-year period by energy experts. It supersedes ASHRAE Standard 90A-1980. Standard 90.1 received extensive public review and was revised in response to all significant comments.

Most of the Hawaii Code is adapted directly from ASHRAE 90.1 with only minor modifications, in particular Articles 5, 6, 9, 10, and 13. These deal with electric equipment, lighting, heating, ventilating, and air-conditioning (HVAC) systems and equipment and the cost budget procedure. Articles 8 and 11 on the building envelope and water heating systems were developed in response to the unique conditions of Hawaii and are significantly different from the parent standard. Another significant difference between the Hawaii Model Energy Code and ASHRAE 90.1-1989 is that the Hawaii code also covers low-rise residential buildings.

While the Code is based on Standard 90.1-1989, it is also influenced by the most recently adopted California codes (Title 24), ASHRAE 90.2P and the USDOE standard for non-residential buildings. In addition, many parts of the code have been developed specifically for the unique conditions of the Islands, in particular the requirements for natural ventilation.

This manual is adapted from the *ASHRAE 90.1-1989 User's Manual.* Many of the figures, tables and examples are taken directly from the ASHRAE document as is much of the text. The State of Hawaii gratefully thanks ASHRAE for allowing the use of these materials. Materials used directly from ASHRAE documents are acknowledged throughout this publication.

Organization of the Code

The code is divided into 13 sections called articles in the code (consistent with ASHRAE 90.1-1989). Sections 1, 2, 3 and 4 are administrative. Sections 5 through 13 are the technical sections. The organization is as follows:

Article 1: Purpose
Article 2: Scope and application of the code
Article 3: Definitions, abbreviations, acronyms and symbols
Article 4: Compliance methods and approaches
Article 5: Motors and provisions for metering of electrical use
Article 6: Lighting systems and controls
Article 7: Not used
Article 8: Building envelope including fenestration (glazing)
Article 9: HVAC systems and controls
Article 10: HVAC equipment
Article 11: Service water heating equipment and systems
Article 12: Central energy management systems
Article 13: Energy cost budget (ECB) method

Organization of this Manual

In general, the chapters of this manual follow the organization of the code, although some of the articles are combined in a single chapter in respect of the common division of work among design professionals and contractors. The organization of the manual follows:

1. Overview. This chapter (the one you are reading) covers Articles 1 through 4 and presents a broad overview of the code and the various methods of compliance.

2. Electrical and Lighting. This chapter is intended for the electrical engineer or contractor and covers Articles 5 and 6 dealing with the design and specification of electrical and lighting equipment and systems.

3. Building Envelope. This chapter is intended for the building designer, design architect or engineer and explains the requirements of Article 8 dealing with building insulation, glazing and natural ventilation.

4. HVAC Systems and Equipment. This chapter is intended for the mechanical engineer or contractor and covers Articles 9, 10 and 12 dealing with the design of air conditioning systems, selection of efficient equipment and energy management systems.

5. Water Heating. This chapter deals with the requirements for water heating systems in both residential and nonresidential buildings (Article 11).

6. Cost Budget Method. This chapter explains the cost budget procedure of Article 13 and includes detailed information on how it is used.

There are six Appendices to the manual. Appendix A is a summary of the requirements for low-rise residential buildings. While it is included as an appendix to this manual, it is really a stand-alone document that explains the requirements for most low-rise residential buildings. This appendix is available as a separate stand-alone publication.

Appendix B is a supplement on how to install and use the LTGSTD computer program on the lighting standard. Appendix C is a supplement on the installation and use of the ENV1 computer program on the building envelope standard. The computer programs are also covered in Chapters 2 and 3 of this manual.

Appendix D contains weather data for several locations. Appendix E describes default equipment performance curves which may be useful in the energy cost budget method of Article 13.

Appendix F is a compliance checklist. On one side it is a form for designers to indicate which compliance method is used. On the other side is a brief list of all the code's requirements.

To avoid confusion with tables in the code which are numbered with the name of the article followed by a sequential number (for instance Table 6-2 is the second table in Article 6), all tables, figures and examples in this manual are numbered with the chapter number followed by an alphabetic letter. Sometimes tables in the code are repeated in the manual. In these cases, the table number in the code is included in parentheses.

Scope

The Code applies to all buildings, residential and non-residential, even if the structures are not air-conditioned. The largest energy savings are attributed to the water heating and lighting requirements, and whether or not a building is air conditioned does not affect the applicability of these requirements. Separate building envelope requirements generally apply for naturally ventilated buildings, however.

The Code totally exempts buildings in the following three categories.

- Buildings or areas of buildings intended primarily for manufacturing, commercial or industrial processing
- Buildings that have a peak design rate of energy use less than 1.0 W/ft^2
- Buildings smaller than 100 ft^2

Building officials can also waive specific requirements for historic buildings when it is determined that the historic nature of the building will be harmed

Table 1-A Scope of Hawaii Model Energy Code

	Non-Residential		Residential	
	A/C	Nat. Vent.	A/C	Nat. Vent.
Electric Power			high-rise only	high-rise only
Lighting			no	no
Air Leakage		no		no
Comfort Ventilation	no			
Roof Heat Gain				
Wall Insulation		no		no
Windows				high-rise only
Skylights				no
HVAC Systems		no	high-rise only	no
HVAC Equipment		no		no
Water Heating				
Energy Management			high-rise only	high-rise only

through the application of one or more of the requirements. In these cases, only those requirements that would damage the historic merit of the building are waived.

The code also applies to new construction in existing buildings. For instance, if interior renovations call for an entirely new lighting system, the lighting standard would apply to the new system. The Code would not apply, of course, to the portion of the building that is not improved. The code applies in a similar manner to the construction of a new HVAC system in existing buildings. See the following chapters for more details on how the code applies to existing buildings.

Compliance Methods

The Code has *basic requirements* that must be met for all buildings. After that, there are three alternative methods of compliance: the *prescriptive*, the *system performance*, and the *energy cost budget* methods. The system performance method is available for lighting, and the building envelope. The designer may choose the method best suited for a particular project. The prescriptive and system performance methods may be used alternately on a section-by-section basis. As no system performance requirements exist for HVAC systems, prescriptive requirements *must* be met for this article unless the energy cost budget method is used. More information on these methods and the basic requirements is presented below.

Basic Requirements

The basic requirements must be met for all projects without exception. Most basic requirements do not influence the size, shape or physical appearance of the building. The following are examples of basic requirements.

- Equipment efficiencies for motors, lighting ballasts, HVAC equipment and water heating equipment
- Equipment load sizing procedures for HVAC and water heating
- Basic controls for lighting, HVAC and water heating systems
- Air leakage and natural ventilation requirements for the building envelope
- Exterior lighting allowances
- Distribution system performance requirements such as duct insulation, duct leakage and pipe insulation
- Metering and monitoring provisions for electrical power and HVAC equipment

Prescriptive Method

The prescriptive method is an option for lighting, the building envelope, and HVAC systems. These requirements are component oriented and represent the simplest most direct method of demonstrating compliance. They include look-up tables with specific values that a particular building component must meet. This procedure is generally the fastest and easiest way to demonstrate compliance. The prescriptive requirements are also the more stringent and less flexible.

System Performance Method

The system performance method is an option for lighting, and the building envelope. These requirements are system oriented and allow trade-off within components of the lighting, and envelope respectively (but not between the two).

The system performance method allows greater design flexibility than the prescriptive method and is easier to apply than the energy cost budget method.

For lighting, the interior lighting power allotment is based on the actual space layout and use. This generally provides for a more accurate power allocation that more closely matches the lighting needs. For the building envelope, a computer program models the building envelope as a system and allows trade-offs between different components. A designer can balance increased window area against higher insulation in the opaque wall. The system performance methods for both lighting and envelope are supported by MS-DOS computer programs.

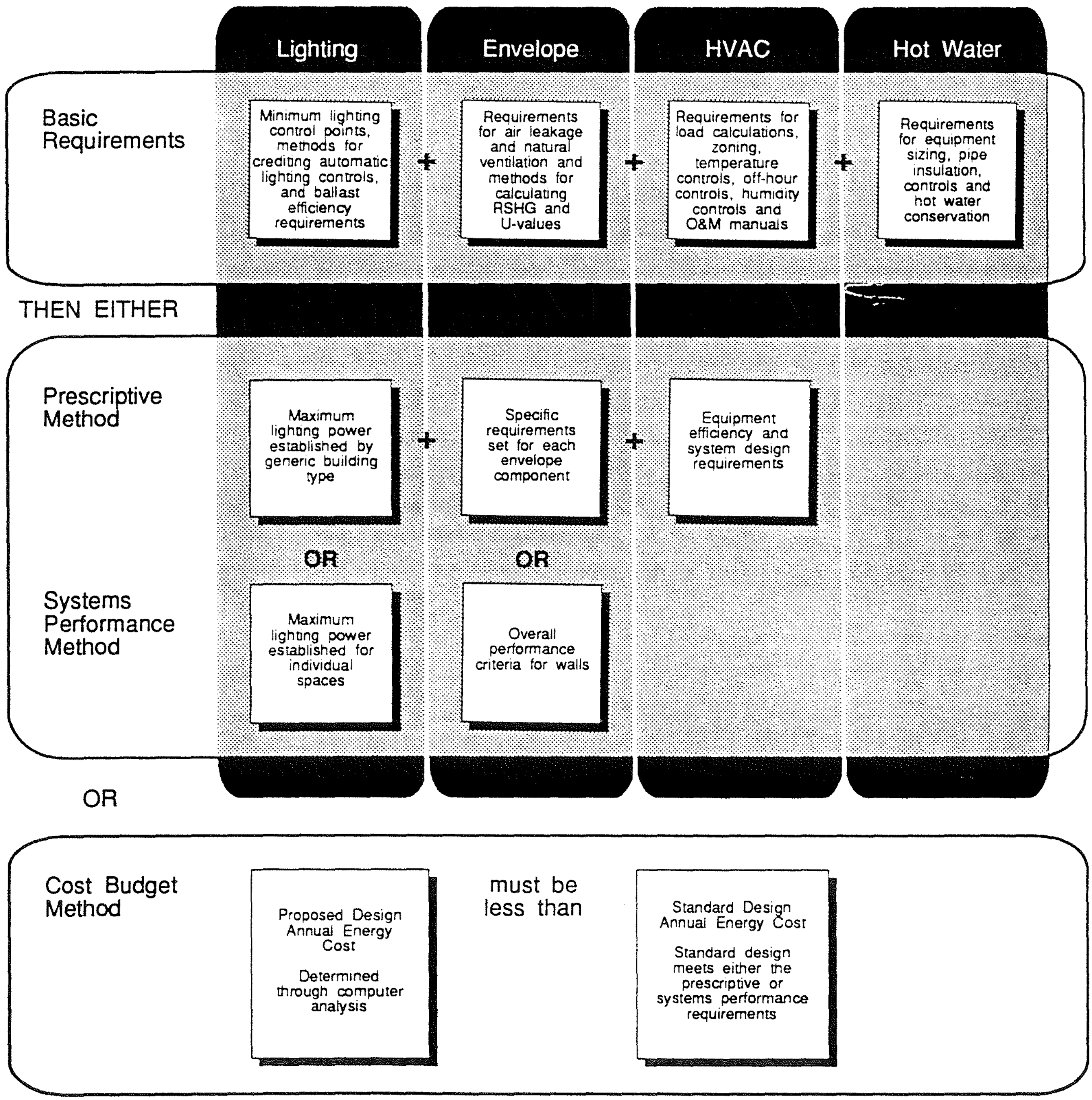
With a modem the two programs are available on the DBEDT bulletin board (586-2496). Join conference #1 and download the files ENV1X.EXE and LTGSTDX.EXE. Otherwise contact DBEDT for information about obtaining a copy of the programs.

Building Energy Cost Budget Method

The energy cost budget method (ECB) allows trade-offs in performance from all elements of the building design except the basic requirements. This method provides the ultimate design flexibility, but requires rigorous computer modeling of two buildings: a budget building and the proposed design. The proposed building is modeled as designed. The budget building is like the proposed building in many aspects, but it must meet either the prescriptive or system performance section of each section. Compliance in the ECB method is achieved if a proposed building design has an annual energy cost that is no higher than that of the budget building.

Using this method, the designer can exceed any prescriptive or system performance requirement thereby allowing for the most design flexibility. The ECB method is exclusive of the prescriptive and system performance methods. Either the design shows compliance under the energy cost budget method or it shows compliance under a combination of prescriptive and system performance methods as previously described.

Figure 1-B Compliance Options
(from ASHRAE Standard 90.1- 1989 User's Manual)



Summary of the Code

Highlights of Residential Requirements

The residential requirements address water heating, ceiling heat gain, and natural ventilation; and when the home is air conditioned, additional requirements are triggered. These requirements are summarized in Figure 1-C and explained in greater detail in the text that follows.

Ceiling Heat Gain

Ceiling constructions must either be insulated or alternatively may use a radiant barrier in combination with a light-colored roof. The actual criteria are expressed as a maximum roof heat gain factor (RHGF). There is a simple equation for RHGF that takes account of insulation levels (U-value, U_r), color (absorptivity, α) and radiant barriers.

This equation is shown below:

$$RHGF = U_r \times \alpha \times RB$$

The maximum RHGF is 0.05 and compliance with this criterion can be achieved by lowering U_r (installing insulation), lowering α (using a light color) and/or installing a radiant barrier (RB). RB is 1.00 for no radiant barrier and 0.33 when a qualifying radiant barrier is installed. To qualify, a radiant barrier must have an emissivity of less than 0.10 and meet other requirements.

Analysis shows that the roof heat gain requirements can be justified economically in air conditioned buildings. They are also justified for natural ventilated buildings because they increase comfort.

Figure 1-C Summary of Residential Requirements

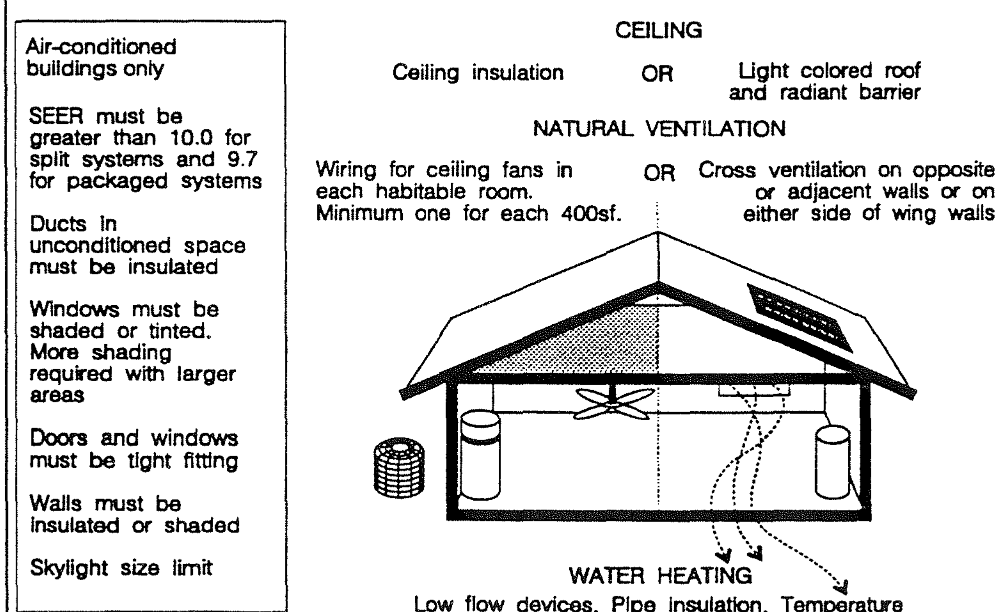
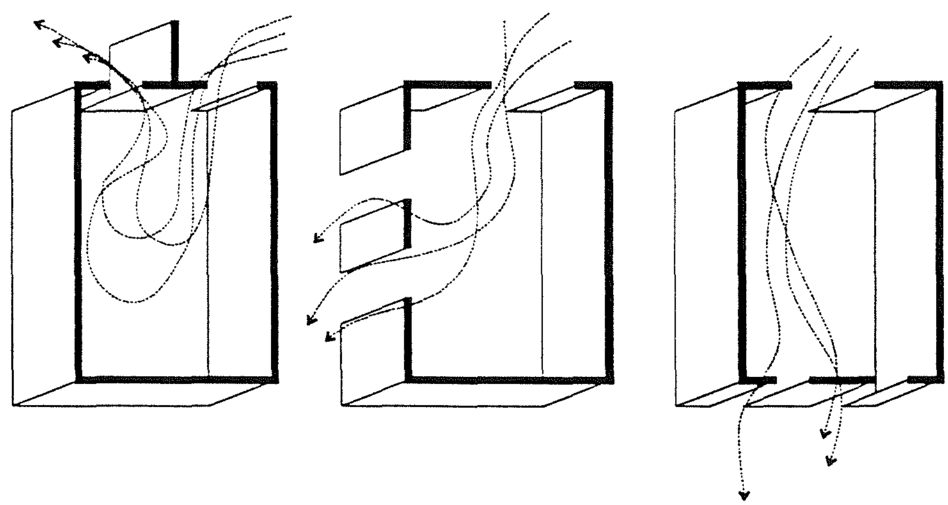


Figure 1-D Methods of Providing Cross Ventilation



Natural Ventilation

The natural ventilation requirements are intended to eliminate (with the help of the roof heat gain requirements) the need for air conditioning. Habitable rooms (kitchens, bedrooms, living areas and dining rooms) must have two operable openings on opposite or adjacent walls for cross ventilation or on opposite sides of a wing wall. The minimum free ventilation area must be at least 12% of the floor area. In addition, louvers or door catches must be installed on interior doors.

Habitable rooms that do not satisfy the natural ventilation requirements must be wired for the future installation of ceiling fans. The wiring must enable wall-mounted fan controls.

Water Heating

Water heating is the major energy user for most Hawaii residences. The Code achieves savings by requiring hot water conservation devices, pipe insulation, and temperature control.

Special Requirements for Air Conditioned Buildings

When air conditioning is installed there are additional requirements for equipment efficiency, heat gain through walls and windows and air leakage.

Equipment Efficiency. Split system air conditioners must have a minimum SEER (Seasonal Energy Efficiency Rating) of 10.0. Packaged air conditioners must have an SEER of at least 9.7. These requirements are consistent with federal law in the NAECA (National Appliance Energy Conservation Act). NAECA also has requirements for room air conditioners and heat pumps.

Wall Insulation or Shading. Walls in air conditioned buildings must either be insulated or shaded to prevent heat gain.

Window Shading. Windows must be shaded with overhangs or other permanent devices, or alternatively, solar gain may be controlled with low-transmission glazing. The requirements become more stringent with larger glass areas. Separate, less stringent requirements are provided for north-facing windows. The residential requirements are similar to the nonresidential requirements which are discussed later in the next section.

Air Leakage. Windows and doors in air conditioned buildings must be tight fitting to minimize air leakage. Jalousie windows are limited to a maximum of 2% of the exterior wall area.

Highlights of Requirements for Hotel Guest Rooms

The requirements for hotel guest rooms are similar to those for residential buildings. The requirements apply to lighting, heat gain into the building envelope and the design of air conditioning and water heating systems. There is a requirement for either natural ventilation or ceiling fans. These requirements are summarized in the figure below and explained in greater detail in the text that follows.

Lighting

Hotel guest rooms are permitted a maximum of 0.7 watts per square foot of floor area. A 300 ft^2 guest room would be allowed 210 watts of lighting. This level requires more use of compact fluorescent lamp sources.

Envelope

The requirement for ceiling heat gain is identical to residential buildings, limited to a maximum of 0.05 Btu/h-ft^2. This requirement can be satisfied by installing insulation or by using a light-colored roof and a radiant barrier. See the discussion on residential requirements for low-rise residential buildings. The ceiling heat gain requirement applies to both air conditioned and naturally ventilated buildings.

The natural ventilation requirements apply to guest rooms which are not air conditioned. The requirements are the same as for residential buildings as described earlier.

Walls must be insulated unless they are shaded by an overhang having a projection factor of at least 0.3 on non-north orientations and 0.2 on north orientations. The shading exception also applies when walls are shaded by building wings, other buildings or terrain.

Solar heat gain through fenestration is limited in the Code by a maximum RSHG (relative solar heat gain) factor. The maximum RSHG depends on the WWR (window wall ratio) and the orientation.

The RSHG criteria for glazing can be satisfied with a combination of fixed shading devices such as overhangs or sidefins, with tinted or reflective glass or with interior or exterior shading devices.

HVAC

Doors leading from guest rooms to outdoor balconies or terraces must have an electrical interlock that shuts off the air conditioner when the door is open.

When air conditioners larger than 10 tons are used for space cooling or compressors larger than 15 hp are used for refrigeration, heat must be recovered from these units to help satisfy the water heating load.

There are other general requirements for the design of HVAC systems that apply to equipment efficiencies, ventilation air and other design features.

Water Heating

Water heating systems face requirements for minimum equipment efficiency, pipe insulation, controls, and low flow devices.

Highlights of Requirements for Nonresidential Buildings

The nonresidential requirements address lighting, heat gain into the building envelope and the design of air conditioning and water heating systems. While the requirements are illustrated in the following figure for office spaces, the requirements are similar for other nonresidential building types.

Lighting

Lighting is the most significant requirement for nonresidential buildings. There are two fundamental requirements. The first is for a minimum level of lighting control to enable efficient operation of the lighting system. The second sets the maximum lighting power based on building/room size and building type or visual tasks.

Figure 1-E Summary of Hotel Guest Room Requirements

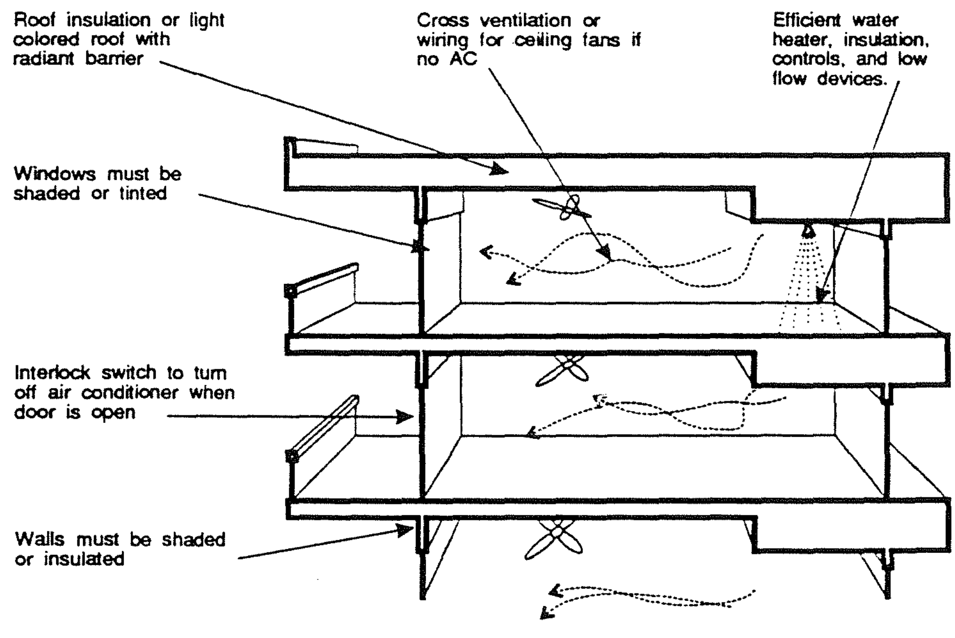
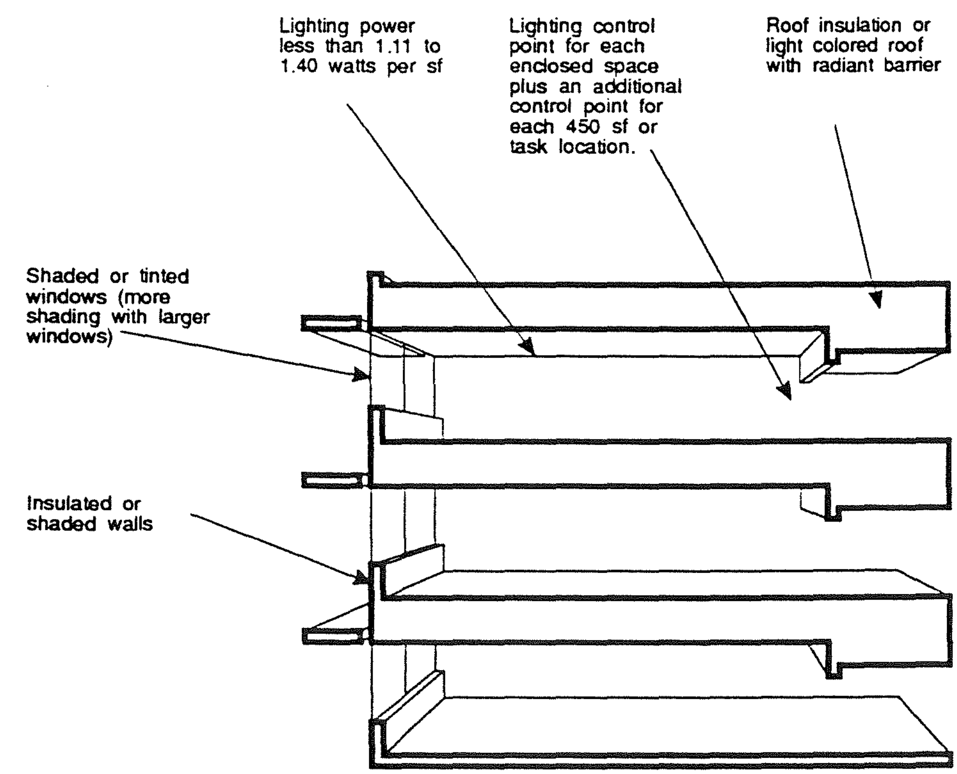


Figure 1-F Summary of Office Requirements



Minimum Control Requirements.

The minimum control requirements are set through the concept of lighting control points. A simple on/off switch is one lighting control point. Occupant sensors, programmable timers and controls that provide three levels of illumination all earn two control points. Automatic or continuous dimming controls and controls that provide four levels of illumination earn three control points.

Each space enclosed by full height partitions must have at least one control point, plus additional control points for each 450 ft^2 of building area or task location. No additional control points are required for storage rooms or lavatories that do not have visual tasks associated with them.

Maximum Lighting Power.

The maximum lighting power density is established in one of two ways. The prescriptive requirements set the limit based on building type or space activity and size. The maximum for offices with this method ranges between 1.4 W/ft^2 for offices less than 2,000 ft^2 to 1.11 W/ft^2 for offices larger than 250,000 ft^2. These requirements are summarized in Table 6-5 of the Code.

To provide some additional flexibility, the system performance method enables the maximum lighting power to be determined for each space in the building and then summed. The second method is more appropriate when a building has special lighting requirements.

With both methods, credit is offered for automatic lighting controls such as daylighting controls or occupant sensors. The credit is offered as a lighting power adjustment factor. This enables compliance with the lighting power requirements to be achieved with efficient equipment, automatic controls or some combination of the two.

Exterior Lighting

There are also requirements for exterior lighting systems. These limits are contained in Table 6-1 and apply to parking lots, exterior walkways, building exteriors and other outdoor lighting requirements. The Code allows more lighting power for parking lots than the most recent Honolulu code. However, the proposed standard is more stringent for building perimeter and other outdoor applications.

2. Electrical and Lighting

This chapter explains the requirements of Articles 5 and 6 of the Hawaii Model Energy Code. Article 5 includes requirements for electrical distribution and motor efficiency. Article 6 includes requirements for lighting equipment and controls. Since responsibility for Articles 5 and 6 often rests with a single entity (the electrical engineer or electrical contractor), they are included here as one chapter.

General Information

Scope

The lighting and electrical equipment requirements apply only to nonresidential buildings, hotels and high-rise residential. None of the requirements apply to low-rise residential buildings and only the electrical requirements apply to high-rise residential buildings.

The lighting standards apply not only to new buildings but also to new lighting systems installed in existing buildings when the space being improved is larger than 1,000 ft^2 or includes an entire floor. Buildings less than 100 ft^2 or those with a peak design rate of less than 1.0 W/ft^2 are exempt from the entire Code, not just lighting. The general exemption also applies to buildings intended primarily for manufacturing or for commercial or industrial processing.

Most lighting for specialized purposes such as theatrical productions, medical procedures and research, signs and emergency lighting is exempt and does not need to be considered. These exempt lighting applications are discussed in greater detail later in this chapter.

Example 2-A Office renovation

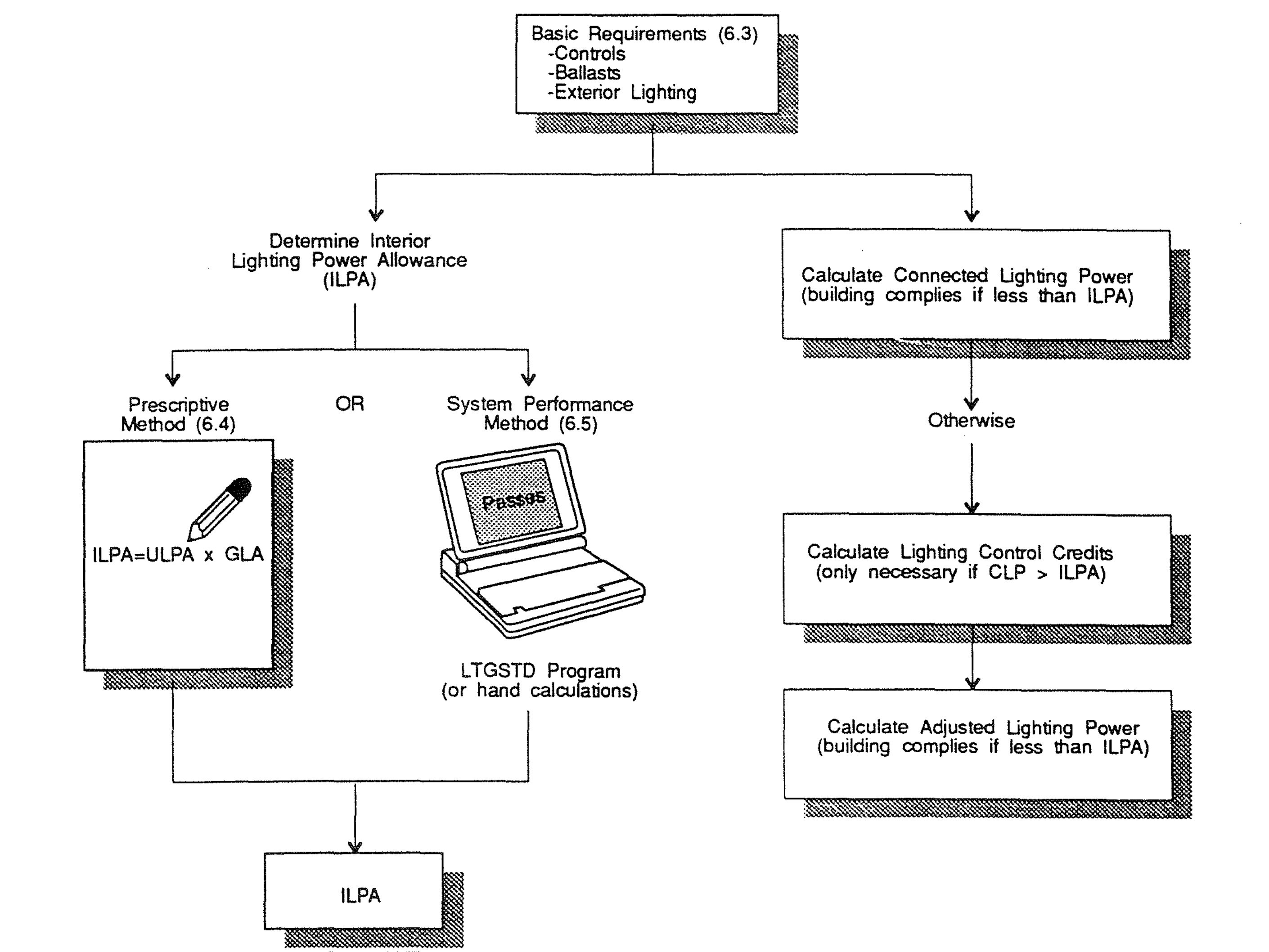
Q

5,000 ft^2 of high-rise office space is to be renovated for a new tenant. Executive offices, covering 1,500 ft^2 along the west perimeter, will get new luminaires with remote-control dimming. In the remaining 3,500 ft^2 of open office space, the existing luminaires will be retrofit with new lamps and ballasts, and prismatic lenses will be installed for a new look. In both cases, the existing wiring will remain unchanged. How do the lighting requirements apply to this renovation?

A

Since the executive offices cover more than 1,000 ft^2 and the luminaires are being completely replaced, this portion of the renovation must comply. However, the requirements apply only to the elements of the system that are being replaced. In this case, the executive offices must meet the lighting power limits because the fixtures are being replaced, but the control point requirements to not apply. The 3,500 ft^2 of open office space is exempt from the lighting code because the existing fixtures and controls are not being replaced.

Figure 2-A Lighting Compliance Options
(adapted from ASHRAE Standard 90.1- 1989 User's Manual)



Methods of Compliance

All of the electrical requirements of Article 5 and many of the lighting requirements of Article 6 are basic requirements and must be satisfied for all buildings. There are three groups of electrical requirements dealing with:

- Electrical distribution and submetering
- Motor efficiency
- Operation and maintenance manuals

The basic requirements for lighting apply to:

- Exterior lighting power
- Lighting controls
- Ballast efficiency

In addition to the basic requirements, the adjusted lighting power (ALP) for interior spaces must be less than the interior lighting power allowance (ILPA). There are two methods to determine the interior lighting power allowance: the prescriptive method and the system performance method. Figure 2-A illustrates these options.

The adjusted lighting power for interior spaces is called "adjusted" because credits may be taken for certain types of automatic lighting controls such as occupant sensors or daylighting controls. When qualifying lighting controls are used, the connected lighting power (CLP) may be reduced by the lighting power control credit (LPCC) to account for the energy savings of these controls. If qualifying lighting controls are not installed, the adjusted lighting power is equal to the connected lighting power. Even when qualifying controls are included in the design, it is not necessary to include them in the calculations if the connected lighting power is less than or equal to the interior lighting power allowance.

Prescriptive Interior Lighting Power Allowance

With the prescriptive method, the interior lighting power allowance (ILPA) is determined by multiplying the gross lighted area of the building by a unit power lighting allowance (ULPA) in watts/ft^2. When the major occupancy in multi-use buildings is greater than 90%, the ULPA for the major occupancy may be used for the entire building, otherwise, the floor area of each use is multiplied times the ULPA for that use.

The prescriptive method is easy to use, quick and straightforward. Its disadvantage is that it is more stringent than the system performance method (allows less lighting power), is limited to the more common building types. Neither is it sensitive to specific space functions or room configurations.

System Performance Interior Lighting Power Allowance

The system performance method is recommended for projects with more complex or atypical lighting needs. It is a more detailed method that applies separate unit power densities (UPD) on a room-by-room or activity-by-activity basis. This method more closely matches lighting power allocation to the requirements of visual work, but requires more effort. A computer program (LTGSTD) is provided to help apply the system performance method. The calculations may also be easily done by hand. Although the system performance ILPA is determined on a space-by-space basis, the connected lighting power (CLP) is always evaluated on a building-wide basis, thus allowing trade-offs between interior lighting systems within a building.

Special Cases

For most buildings, the application of the Hawaii Model Energy Code is straightforward. This section discusses the circumstances of those special cases that are not.

Trade-offs Between Exterior and Interior Lighting

Exterior and interior lighting systems must comply separately with their respective requirements. Trade-offs between the two are not allowed. In fact, since the exterior lighting power limits are a basic requirement, they may not be exceeded even if the energy cost budget method is used (see Chapter 6).

Multibuilding Facilities

Each building in campus-like facilities must comply separately with the interior lighting power requirements, even if they are covered under a single building permit. The exterior lighting power allowance, however, applies for the entire site.

Speculative Buildings

Speculative buildings are buildings that are built before the tenants are known. The initial building permit application usually includes just the shell and core with lighting installed only for the common areas of the building – the corridors, toilets, stairwells and lobby. Lighting for tenant spaces is provided as part of the tenant improvements and is often customized for each tenant. Either the prescriptive or systems performance method may be used with speculative buildings, but each phase of construction must separately satisfy the requirements of the Code.

Shell Buildings

Shell buildings are built before the building's use is known. The space could become light manufacturing, office, warehouse or any other use depending on the requirements of the tenant. In those cases where the developer wants to install a lighting system before the use is known, the ILPA should be set at 0.2 W/ft^2, the allowance for unlisted spaces from the system performance method. However, the lighting system is rarely installed in shell buildings before the space is leased. After it is leased, the space use is known and either the prescriptive or system performance method may be used to set the ILPA.

Garages

A covered garage, even though it is usually unconditioned space, is treated as interior space and is included as part of the interior adjusted lighting power. Open parking lots (including roof top parking), however, are treated as exterior lighting.

Principles Underlying Intent

Electric lighting consumes a significant amount of energy in Hawaii. In office buildings, lighting represents 40 to 45% of energy used. Lighting also increases cooling loads because it adds heat to buildings. To remove the heat from lighting, the building's cooling system consumes additional energy. As a rule-of-thumb, for each 100 kWh of lighting energy, the air conditioner will use another 20 to 30 kWh to remove the heat.

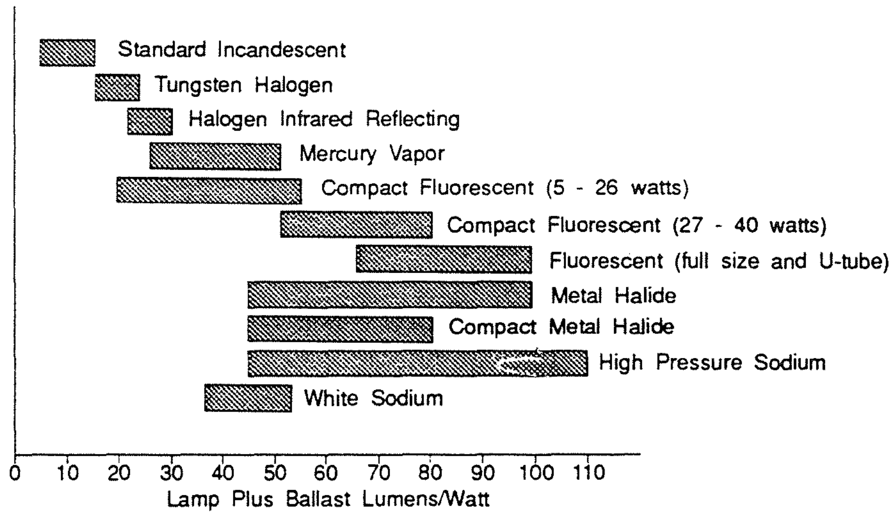
Lighting systems can be designed to reduce energy use and associated cooling loads significantly without compromising lighting quality or quantity. One way this can be achieved is through the use of efficient lighting sources. Figure 2-B compares the efficacy (lumens of light output per watt of electric input) of a number of common lighting sources. Each bar represents the efficacy range for each source. Modern fluorescent lighting systems (the right side of the bar) can provide the same quantity of light as older fluorescent lighting (the left side of the bar) while about one-half the energy. Modern compact fluorescent lighting is four to five times more efficient than the traditional incandescent lighting it replaces.

The Hawaii Model Energy Code is intended to restrict use of inefficient equipment and to encourage efficient lighting design. This is achieved through lighting power allowances. The lighting designer is given an allowance based on the space or building use. Compliance is achieved by installing a lighting system that requires less lighting power than the allowance. This approach provides design flexibility while maintaining a minimum level of efficiency.

The Code also requires, or in some cases encourages, better lighting controls. Lighting controls save energy by reducing the amount of operating time (timeclocks or occupant sensors) and/or reducing the power consumption (dimming controls).

Meeting the requirements of the Code assures only a minimum level of efficiency. Greater efficiency can be cost effective in many buildings (up to 60%-80% over that required by the Code). Designers are encouraged to go beyond the minimum levels of efficiency required by the Code whenever possible.

Figure 2-B Lighting Source Efficacies
(adapted from ASHRAE Standard 90.1- 1989 User's Manual)



Lighting power allowances are based on conventional designs and equipment. Most general lighting power allowances are based on fluorescent sources using magnetic ballasts and standard T-12 fluorescent lamps. Lighting power allowances are based on incandescent lamps only when dimming, point-source directivity and/or critical color rendering are required. The use of modern equipment such as T-8 lamps, electronic ballasts, compact fluorescent lamps and high intensity discharge (HID) lamps will result in designs that are significantly more efficient than required by the Code. On the other hand, it is unlikely that designs using mostly incandescent lamps and/or inefficient lighting fixtures will comply with the lighting allowances while maintaining acceptable illumination levels.

Compliance with the Hawaii Model Energy Code does not assure that adequate illumination is provided or that lighting quality is maintained. The purpose of the Code is to set limits on the amount of lighting power that may be installed. While it is the consensus of experts that lighting quality can be achieved within the limits set by the Hawaii Model Energy Code, it is the responsibility of the designer to provide lighting quality and adequate illumination for all visual work. Quality lighting may require lighter wall or ceiling surfaces and in some cases require a greater initial investment.

Table 2-A Acronyms Used with Lighting Code

(from ASHRAE Standard 90.1- 1989 User's Manual)

AF	Area factor. An adjustment used with the systems performance method to account for the size and shape of a specific room.
ALP	Adjusted lighting power. This is the interior connected lighting power (CLP) less the lighting power control credits (LPCC).
CLP	Connected lighting power. The sum of all interior lighting power that is not exempt.
EPLA	Exterior lighting power allowance. The maximum lighting power that may be used for exterior lighting.
GLA	Gross lighted area. The lighted floor area of the building measured to inside wall surfaces. Used to calculate ILPA with prescriptive method.
ILPA	Interior lighting power allowance. The connected lighting power or the adjusted lighting power must be less than this value which may be determined by either the prescriptive or systems performance method.
LPCC	Lighting power control credit. The benefit of qualifying automatic lighting controls expressed as an equivalent reduction in installed lighting power. For a single control circuit, the LPCC = CLP x PAF.
PAF	Power adjustment factor. The fraction of lighting energy that is expected to be saved from the installation of a qualifying automatic lighting control. See LPCC.
ULPA	Unit lighting power allowance. The maximum watts per ft^2 of lighting for a specific building type, from the prescriptive method The prescriptive ILPA is determined by multiplying the gross lighted area by the ULPA.
UPD	Unit power density. The maximum watts per ft^2 of lighting for a specific building space function or activity, from the system performance method. The system performance ILPA is determined by floor area of each space or group of spaces by the UPD and the appropriate AF.

Note: Table 3.1 of the Code has a complete list of acronyms.

Basic Requirements

The basic electrical requirements of Article 5 deal with electrical distribution and submetering, electric motor efficiency and operation and maintenance manuals. The basic requirements for lighting (Article 6) address interior lighting controls, exterior lighting controls, exterior lighting power and ballast efficiency. They apply when either the prescriptive or systems performance method is used to determine the interior lighting power allowance.

Electrical Distribution and Submetering

These requirements apply to all buildings with a connected electrical load over 250 kVA (usually buildings greater than about 50,000 ft^2). The electrical load includes all equipment powered within the building. For such buildings, the Code requires that electric power feeders be divided by end use and by tenant so that separate metering can easily be accommodated. If users can track their energy use, it is easier for them operate their systems and equipment efficiently and to determine cost effective investments in conservation.

Subdivision of feeders and the subsequent metering of these feeders does not save energy directly but it can provide an incentive to save energy. This is particularly important in multi-tenant buildings. A tenant who receives a lump sum monthly charge for building services (HVAC, electrical, service water heating and rent) is less likely to conserve energy than one that pays the monthly bills for utility services directly. Furthermore, by subdividing feeders by end use, a cost conscious building owner or tenant can more easily target a specific building system for energy conserving retrofit. The impact of educational provisions, such as the requirements for end use metering, is hard to quantify; however, it could easily equal or exceed all of the mandatory measures in the Code.

Subdivided Service By Use

Electrical feeders are required to be subdivided by end use according to three categories:

- Lighting and receptacle loads
- HVAC systems and equipment
- Various loads including service water heating, elevators and special equipment/systems of more than 20 kW.

This last category includes individual equipment or systems which independently draw 20 kW or more. Examples include central computer systems (commonly fed through an uninterruptable power supply), printing equipment, kitchen equipment and baling presses. Smaller equipment such as desktop computers, small printers and small copying machines can be included with the receptacle loads.

Feeders can serve equipment systems from different categories where 90 percent of the load or more is from the predominant category.

Subdivided Service For Tenant Spaces

In multi-tenant buildings, each tenant having a connected load of 100 kVA or more must be capable of being check metered. Permanent electrical meters are not required, but large tenants must be served through separate feeders

Example 2-B Subdivision of Feeders

Q

A medium size retail space has 300 kVA of connected electrical load. This load is divided into the following uses: 50 percent for lighting and receptacle loads, 45 percent for HVAC systems and equipment and the remaining 5 percent for the service water heating system. How many separate feeders are required for this project?

A

As the connected electrical load of this building exceeds 250 kVA it must meet the requirement of this section for subdivision of feeders. Only two feeders are required: one serving the lighting and receptacles; a second serving the HVAC systems and equipment. The service water heating load can be combined with either of the two above, as it is less than 10 percent of either.

Example 2-C Subdivision of Feeders

Q

If the building described in Example 2-A had only 200 kVA of connected electrical load, what subdivision of feeders would be required?

A

None. As the total connected electrical load is less than 250 kVA this building is not required to have any subdivision of feeders.

Example 2-D Subdivision of Feeders for a Water-Loop Unitary Air Conditioner System in a Multi-Tenant building

Q

A water loop unitary air conditioner system consists of a central cooling tower, and loop pumps which circulate water through water-loop air conditioners. Some of the water-loop air conditioners serve central circulation spaces within the building. Other water loop air conditioners are in the tenant spaces. Which systems should be fed from the tenant electrical feeders?

A

Those units which serve the tenant space. The central equipment, including the cooling tower, circulation pumps, and water loop air-conditioning units that serve common areas should be fed through the main building feeders for HVAC systems and equipment. The water-loop air-conditioning units that serve individual tenants should be connected and fed through the electrical feeders for that individual tenant's HVAC system and equipment.

Example 2-E Subdivision of Feeders for Tenant Spaces with a Booster Heater on a Central Service Water Heating System

Q

A tenant in a multi-tenant building installs an electric booster heater on a central service water heating system. Should the booster heater be connected to the tenant's electrical feeders?

A

Yes. As the booster heater serves the tenant's needs, this system should be fed from the tenant's electrical system.

which are accessible for portable meters or future connection of permanent meters.

Where a central HVAC or service water heating system serves more than one tenant, that system can be metered with the main building. However, HVAC or service water heating equipment that is installed in the tenant space and that serves that tenant should be fed through that tenant's feeders.

While not required by the Code, it is recommended that each tenant in multi-tenant buildings be submetered regardless of the size of that tenant. It is further recommended that service for large, individual tenants be further subdivided by the use categories previously described. This is not a requirement of the Code, but will help each tenant to save energy.

Provisions For Metering

Each subdivided feeder must have either a permanent electrical meter, provisions for installation of a permanent meter, or provision for a portable meter. Where permanent meters are not installed, provisions for future installation or portable meters can be provided in either a dedicated electrical cabinet through which the feeders pass or within an electrical cabinet such as a breaker panel.

Dedicated panels must be clearly identified as to the measuring function available. In either case, there must be sufficient room to attach either a clamp-on or split core transformer on each feeder.

Electric Motors

Electric motors are an excellent investment in energy efficiency. Electric motors are used for a variety of purposes in buildings, including HVAC fans, HVAC pumps, open compressors, service water heating pumps, escalators, elevators, conveyors and lifts. Motors are available in a wide range of efficiencies. In motors, the electrical energy which is not converted to power is dissipated as heat. Depending on the motor type, size and service, this waste heat can account for 1% to 30% of the energy used by the motor.

Table 5-1 of the Code has minimum full load efficiency requirements for single speed polyphase motors of one horsepower or larger. The efficiency requirements depend on the expected usage in hours per year and on the speed. There are no requirements for motors that are expected to operate for less than 500 hours per year. The required motor efficiencies are classified by the National Electrical Manufacturers Association (NEMA) as "energy efficient". Exceptions are provided for motors that are multi-speed and for motors used as components of equipment where those motors are part of the efficiency ratings of the equipment that meets the requirements of Article 10.

Additional Motor Recommendations

Although not a requirement of the Code it is recommended that motors be sized to not exceed the anticipated load by more than 25%. Variable speed drives are also recommended in preference to throttling bypass or similar devices for variable flow systems. This applies to both air and hydronic HVAC systems.

Example 2-F Minimum Motor Efficiencies

Q

A water-loop unit air conditioner system serving a multi-tenant office building has two circulation pumps, each of which have a 5 hp open drip-proof motor (4-pole, 1800 rpm). What are the minimum efficiencies required for these motors?

A

As these motors are over one horsepower, and as they are expected to operate more than 1000 hours a year, they must have a nominal efficiency equal to or in excess of 87.5% (Table 5-1).

Example 2-G Minimum Motor Efficiencies

Q

A packaged air conditioning unit has a 10 hp standard efficiency fan motor that does not meet or exceed the nominal efficiency requirements of Table 5-1. If this unit as a whole meets or exceeds requirements of Article 10, will it comply?

A

Yes. This unit complies as this unit's ratings include the electrical use of the fan motor, and as the unit complies with the requirements of Article 10. However, if the manufacturer offers the same unit with a high or premium efficiency motor, the designer may want to consider specifying this option, as it is likely to be cost effective.

Example 2-H Minimum Motor Efficiencies.

Q

A two-speed 7-1/2 hp motor issued for an exhaust fan which serves a gymnasium. Is this motor required to meet the nominal efficiencies of Table 5-1?

A

No. As this is a two-speed motor, it is not required to meet the minimal efficiencies of Table 5-1.

Operation And Maintenance Information

The designer or contractor is required to provide specific operation and maintenance information about the building electrical distribution system to the building owner. This information must be collected in a manual which includes:

- A single-line diagram of the as-built building electrical distribution system. The locations for permanent meters or provisions for check metering must be noted on this single-line diagram.
- Schematic diagrams of electrical controls systems other than HVAC control systems which are covered under the requirements of Section 12 of the Code.
- Any operational maintenance information for electrical equipment which was provided by the manufacturer of that equipment.

Interior Lighting Controls

The purpose of the lighting control requirements is to enable lighting to be turned off when it is not needed. Accessible controls are required for each lighting system and a separately controlled lighting system must serve each enclosed space. In addition, multiple points of control are required for separate tasks or spaces. These are explained in greater detail below.

Control Required for each Lighting System

Each lighting system must have some means of control, except for emergency and exit lighting. Acceptable means of control include manual switches, programmable timeclocks, photocells and occupant sensors. Circuit breakers, fuses and other devices not intended and/or suited for lighting control fail to satisfy this requirement.

Enclosed Spaces

Each space enclosed by walls or ceiling height partitions shall be provided with controls that together or singly, are capable of turning off all the lights within that space. There is an exception for continuous lighting required for security purposes.

Control Accessibility

Lighting controls must be in the room where the lighting system is located and they must be readily accessible. They should be visible and easily operated by the occupants of the space. The Code recognizes several cases where this requirement is not reasonable or practical; exceptions include:

- Lighting controls for spaces that must be used as a whole
- Automatic controls
- Programmable controls
- Controls requiring trained operators
- Controls for safety hazards and security

Lighting Control Points

The Hawaii Model Energy Code uses a scoring system for lighting controls where each type of control is awarded a certain number of control points. A simple on/off control earns one control point. Occupant sensors, programmable timers (within the space) and three-level switches earn two control points, while other types of controls including four-level switches, preset dimming systems and continuous dimming systems earn three control points.

Although one might think of control points as locations (points) of control, it is more accurate to think of them as scoring points. Each control point is indicative of its ability to save energy – the more points the more efficiently the lighting system can operate. The number of control points associated with various types of lighting controls are presented in the Code in Table 6-2 and repeated here as Table 2-B.

Table 2-B Control Types and Equivalent Control Points
(Table 6-2 in the Code)

Type Of Control	Equivalent No. of Control Points
Manually operated on-off switch	1
Occupancy sensor	2
Timer--programmable from the space being controlled	2
Three–level, including off, step control or preset dimming	2
Four–level, including off, step control or preset dimming	3
Automatic or continuous dimming	3

The number of control points required in each space is determined by the following rules.

- Start with one control point for each interior room (space enclosed by walls or ceiling height partitions)
- Add one additional control point for each task location or for each 450 ft^2 of space whichever is less.

With the 450 ft^2 rule, the required number of control points is rounded to the next highest whole number. Each space within the building must separately meet its control point requirements. A private office will generally require at least two control points (one for the enclosed space and one for the task). This means that each private office must have a switch that is capable of providing bi-level illumination (through use of two switches, or one), an occupant sensor or other controls from Table 2-B that earn at least two control points. Locally switched permanently-mounted task lights (e.g. in furniture systems), count as a qualifying lighting control point.

Figure 2-C shows a partial floor plan of a typical office building and shows how the control point methodology is applied.

An exception allows the number of required control points to be reduced by one for each 0.70 watt reduction in interior lighting power allowance (ILPA).

The control point requirements are not applicable to exterior lighting systems.

Minimum Number of Controls

Regardless of the control points required or earned, at least one control must be provided for each 1,500 W of connected lighting power. An important exception to this requirement is for large spaces that must be used as a whole such as public lobbies of office buildings, hotels and hospitals, retail and department stores, warehouses and storerooms and service corridors under central supervision. In these cases additional switches (for each 1,500 watts) do not save enough energy to warrant them being required. However, the spaces must be provided with at least three control points.

Multiple Switch Locations

It is *not permitted* to count two 3-way switches on one circuit as two devices for the purposes of control points or minimum switch requirements.

Figure 2-C Control Requirements for a Typical Office Building
(dimensions in feet)
(from ASHRAE Standard 90.1- 1989 User's Manual)

Each 10 x 15 private office with one task needs two control points

a. First control required

b: Additional control for task or fraction of 450 ft²

Large 30 x 40 meeting rooms need at least two but no more than four lighting control points

a. First control required

b. Additional control for each task or for each 450 ft², whichever is less

20 x 30 conference room needs at least two control points

a. First control required

b. Additional control for each task or 450 ft², whichever is less. The number of visual tasks in the conference room will depend on the specific design.

30 x 40 mail room with four task locations needs four lighting control points

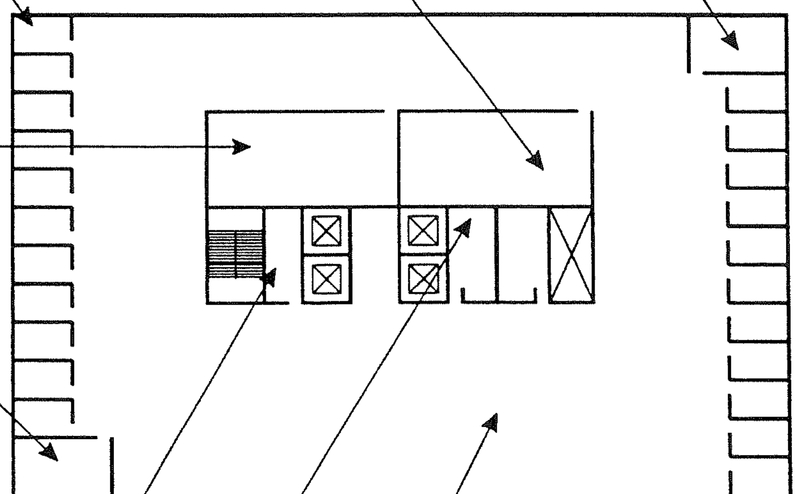
a. First control required

b. Additional control point for each task or 450 ft², whichever is less. In this case the 450 ft² rule results in three additional control points, fewer than the number of tasks.

20 x 30 work area with three tasks needs three control points

a. First control required

b. Additional control points for each task or 450 ft² whichever is less. In this case, the 450 ft² rule results in two additional control points, which is less than the



Storage room needs one control point

a. First control required

b. No tasks

Lavatories need one control point each

a. First control required

b. No visual tasks

40 x 100 open office with 50 tasks requires ten lighting control points

a. First control required

b. Additional control for each 450 ft² which is less than the number of tasks

Example 2-I Accessibility and Location of Lighting Controls

Q

Can lighting for corridors in a mall be grouped and switched from a remote location?

A

Yes, since the space is used as a whole. By switching from a remote location, any unusual appearance or functional discrepancy caused by partial lighting can be avoided.

Q

Does a programmable time device for a retail store need to be located in the store?

A

No, programmable or automatic controls are exempt from this requirement and may be located in a remote location.

Q

Do lighting controls in airports, building lobbies, banks, libraries and department stores need to be accessible?

A

No, there is an exception to the accessibility requirement for safety and security reasons.

Example 2-J Required Lighting Control Points

Q

A store room of 120 ft^2 has storage on walls all around the room. How many control points are required?

A

One control point. The Code (in Article 3) defines a "task location" as an area where significant visual functions are performed and where lighting is required above and beyond that required for general ambient use. A storage room does not have any significant visual functions, and therefore, only one point is required for the room itself.

Q

A classroom has 30 desks and is 600 ft^2. How many control points are required?

A

Three control points. The 30 desks are not considered 30 separate tasks but one common group of tasks. The required control points are calculated as follows: one point for the room itself and two points for groups of tasks of 450 ft^2 (or less). Although 600 ft^2/450 ft^2 = 1.33 < 2, control points are always rounded up to the next significant digit.

Example 2-J Required Lighting Control Points (continued)

Q

An airport waiting area of 1,600 ft^2 has 150 seats. The lighting power is about 1,900 watts. How many control points are required?

A

The control point requirements do not apply in this case because of the exception for rooms which must be controlled together. The lights of this waiting area may be controlled as a unit and the lighting controls may be remote from the room.

Q

A retail department store has literally hundreds of visual tasks. How many points and controls are required?

A

The control point requirements do not apply in this case because of the exception for rooms which must be controlled together. The lights of a retail store may be controlled as a unit and the lighting controls may be in a remote location.

Hotel/Motel Guest Rooms

A master lighting switch must be located near the entrance door to a hotel or motel room. The master switch must operate all permanently installed lighting and all switched receptacles, generally in series with local controls on all these devices. For multiroom suites, a master light switch at each room door is an acceptable alternative to having all lights switched at the suite entry door.

Luminaires Under Skylights

All luminaires which direct more than half their light into daylighted zones beneath skylights must be controlled by daylight sensing controls or be switched independently of luminaires in non-daylighted zones. See Article 3 of the Code for the definition of daylighted zone.

Exterior Lighting Controls

With the exception of exterior lighting designed for 24-hour operation, all exterior lighting must be controlled by photocells, time switches or a combination of the two. Time switches must be 7-day, astronomical (or have some means of seasonal compensation). There must also be a power backup to enable accurate time keeping through a minimum 4-hour power loss.

Traditionally, exterior lights have been controlled by electro-mechanical clocks with mechanical trippers which toggle circuit switches. These devices typically are equipped with a manual override. Many of these traditional devices do not have either seasonal correction or 4-hour backup and will *not* meet the requirements of the Code. The following devices will meet the requirements:

- 7-day electrically-driven, mechanical clock with trippers, astronomical dial and 4-hour spring-wound storage
- 7-day or calendar year, electronic programmable time switch with astronomic correction and battery backup
- Either of the above with a photocell (in lieu of astronomical correction)

Of these, the last is best since it automatically and continuously compensates for changes in the seasons, and has the redundancy of the timeclock control which will operate if the photosensor fails.

Exterior Lighting Power

Exterior lighting power must be less than the exterior lighting power allowance (ELPA). Trade-offs are not permitted between exterior and interior lighting. For multibuilding facilities, the exterior lighting power allowance (ELPA) applies to the entire site and trade-offs are permitted between exterior lighting systems on the site.

What is Covered

Most exterior lighting is covered by the Code including all permanent lighting fixtures intended for lighting the building and its grounds.

Building-Mounted Exterior Lighting. All lighting mounted on the building, less specific exceptions as noted below, is covered. This generally means all lanterns, soffit lights, floodlights, step lights, wall packs and any decorative lighting such as neon outlining, low-voltage light strips and ornamental pendants and globes.

Grounds, Roads, Parking Lots and Other Exterior Lighting. All lighting on the building site, less specific exceptions as noted below, is covered. This generally includes pole-mounted lighting, landscape lighting, bollards, step lights, wall packs and all other lighting for the roads, walks, parking lots, gardens, trees and other portions of the site. Note that lighting not powered by the building electrical system, such as municipal street lights, is exempt.

Open-air parking lots, rooftop parking and carports are included in the exterior lighting requirements. Covered parking garages are part of the interior lighting requirements.

Exempt Exterior Lighting

Article 6 of the Code does not regulate lighting over which the designer has little choice or control, as described below. Lighting for safety, security or commercial needs is also exempt. The following are specific lighting applications exempt by the Code.

Emergency Lights, Exit Signs and Mandatory Safety or Security Lights. If a code or ordinance requires lighting for safety or security, then it is generally exempt. It is *not* exempt if it is used as part of non-mandated lighting as well. An emergency egress light is exempt if it is normally off and switched through life-safety controls; however, if the light also serves as a general light source, it is *not* exempt. Typically exempt lighting also includes exit signs, security lights (such as for automatic teller machines) and other lights required by security or safety officials.

Sign Lights. Both self-contained and external illumination for signs are exempt.

Exterior Lighting. Outdoor lighting for a wide variety of special situations is exempt, including:

- Outdoor Manufacturing, commercial greenhouses and processing facilities. This in general is meant to exempt outdoor commercial, agricultural and industrial work areas, ranging from nighttime farming activities to refineries.
- Outdoor athletic facilities. Lighting for outdoor sports of all kinds is exempt.
- Exterior lighting for public monuments
- Lighting for dwelling units. Note that exterior lighting as well as interior lighting for dwelling units is exempt.

Definitions Used with Exterior Lighting Calculations

The allowance for some of these areas involves judgment. The following definitions are provided as a guide:

Exit. A door or group of doors to a building not ordinarily used as an entrance and primarily used as an emergency, nighttime or convenience exit.

Entrance (without canopy). A door or group of doors to a building ordinarily used by tenants or the public to enter the building for normal use or business, but having no ornamental or functional canopy or shelter.

Entrance (with canopy). A door or group of doors to a building with an exterior awning, soffit, canopy or ornamental or functional structure generally signifying a "main" or "proper" entrance to a building. A canopy does not have to be shelter; the major issue here is identification or marketing.

Public Exterior Areas. Public areas are intended to mean those used by the occasional and/or unfamiliar user of the building. For instance, parking and roads for hotels, airports, shopping centers, etc. are "public." Also public are the roads leading to a private building, such as an office building, plus the visitor parking and all walks leading into the main entry.

Private Exterior Areas. Private exterior areas are those whose users are frequent and/or familiar users of the facility. Typical situations include private parking lots and drives to them.

Exterior Lighting Power Allowance

To determine exterior lighting compliance the designer must calculate both the exterior connected lighting power (CLP) of the proposed design and the exterior lighting power allowance (ELPA). Compliance is achieved if the exterior CLP is less than or equal to the ELPA.

The exterior CLP is calculated by summing the exterior lighting power for all luminaires that are included in the scope of the exterior lighting requirements.

The ELPA is calculated by multiplying each lighted area (or length of door opening) by the appropriate exterior lighting power allowance from Table 2-1. This table is repeated as Table 2-C below.

There are three types of measurements used in determining ELPA:

Horizontal Areas. Typically flat or rolling area of grounds, driveways, lots, gardens or parks are measured from site plans. In general, measure and compute the area as if the site were flat. Sites with extreme topography can be allowed a larger area than the horizontal projection due to the actual area of the land's contours; however, unless a sophisticated and accurate method for determining surface area is used, then the "flat" condition must be assumed. In the case of canopies, the area of the canopy ceiling measured in the flat plane

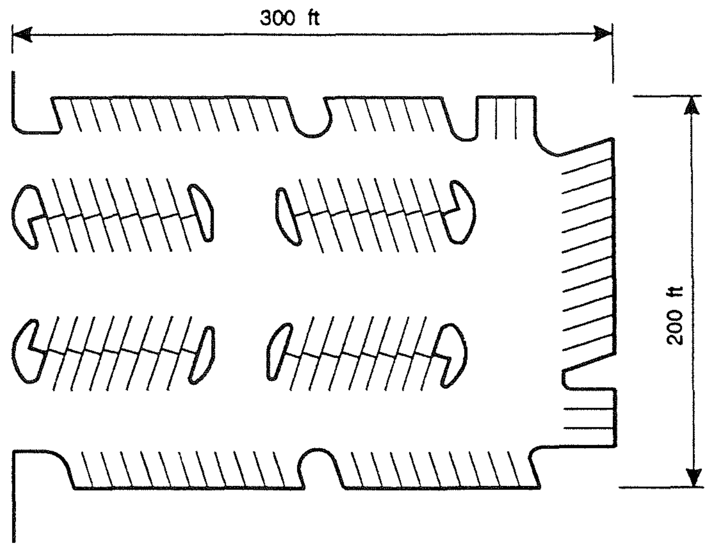
Table 2-C Exterior Lighting Unit Power Allowances
(Table 6-1 in the Code)

Area Description	Allowances
Exit (with or without canopy)	25 W/lf of door opening
Entrance (without canopy)	30 W/lf of door opening
Entrance (with canopy)	
High traffic (retail, hotel, airport, theater, etc.)	10 W/ft^2 of canopied area
Light traffic (hospital, office, school, etc.)	4 W/ft^2 of canopied area
Loading area	0.40 W/ft^2
Loading door	20 W/lf of door opening
Building exterior surfaces/facades	0.25 W/ft^2 of surface area to be illuminated
Storage and non-manufacturing work areas	0.20 W/ft^2
Other activity areas for casual use such as picnic grounds, gardens, parks, and other landscaped areas	0.10 W/ft^2
Private driveways/walkways	0.10 W/ft^2
Public driveways/walkways	0.15 W/ft^2
Private parking lots	0.12 W/ft^2
Public parking lots	0.18 W/ft^2

Example 2-K Exterior Lighting - Parking Lot.

Q

A parking lot measures 200 x 300 ft, with planters between parking aisles. What is the area of the lot and the lighting power allowance?



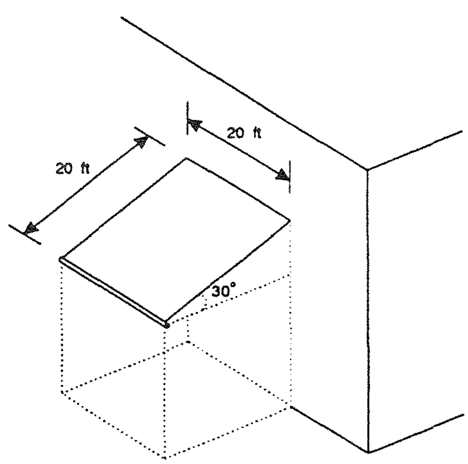
A

The area of the parking lot is 200 by 300 ft, or 60,000 ft^2. The planter medians between the parking aisles are included as part of the parking lot area, but, planting areas around the lot are not. The exterior lighting unit power allowance is 0.12 W/ft^2 (private) or 0.18 W/ft^2 (public). The exterior lighting power allowance is, therefore, 7,200 watts (private) or 10,800 watts (public). In addition, the walkways, drives and intersections associated with the lot are also allowed lighting power, either 0.10 (private) or 0.15 (public) W/ft^2. The parking lot is public if it is available for use by the general public; it is private if it is intended for use solely by the employees or tenants.

Example 2-L Exterior Lighting - Roof Canopy

Q

A roof canopy slopes at an angle of 30 degrees and has an absolute surface area of 20 ft × 20 ft = 400 ft^2. What is the canopy area for power allowance calculations?



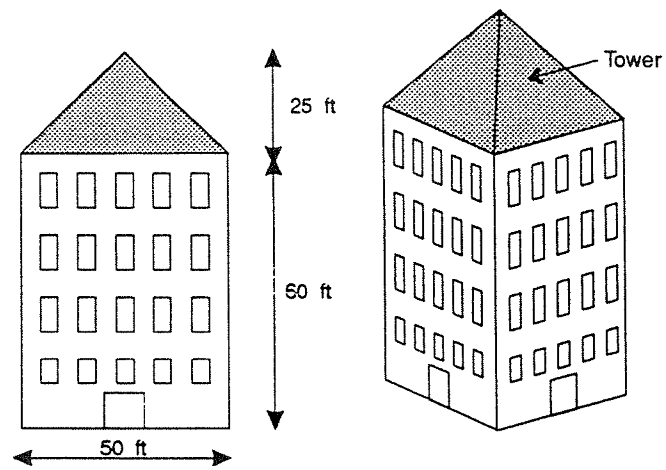
A

The projected area below the canopy is given by: 20 x 20 x cos 30°=20 x 20 x 0.866=346.4 ft^2. If the canopy is dimensioned in plan the measurements are 17 ft 4 in. by 20 ft.

Example 2-M Exterior Lighting - Building Facade

Q

A building consists of a four-sided pyramid atop a four-sided tower with no cornices or soffits. What building facade area shall be used for determining the exterior lighting power allowance?



Perspective

A

If all sides of the building as well as the pyramid are intended to be illuminated the entire surface area of the building may used as the basis of the ELPA. Each vertical surface is 60 by 50 ft or 3,000 ft^2 for a total area of 12,000 ft^2. Each triangular face of the pyramid is 437 ft^2 for a total area of 1,748 ft^2. The unit power allowance is 0.25 W/ft^2 of surface area to be illuminated, therefore, the maximum power allowance for the building is 3,437 watts. Please note that the unit power allowance only applies to the surface area intended to be illuminated, not the entire surface.

Example 2-N Exterior Lighting - Building Cornice

Q

A cornice which is designed to be illuminated protrudes from the facade of a building. Does it receive any special power allowance?

A

It receives a power allowance based on its area; since it protrudes, it will have a larger area than the flat building facade from which it hangs. Ordinarily, the cornice top is not intended to be illuminated and therefore its area is ignored.

Example 2-O Exterior Lighting Power - Office Park

Q

A three building site has the following elements:

- A four–story parking garage with the top level open. The building footprint is 10,000 ft^2. The garage is for employees
- A visitor parking lot of 5,000 ft^2
- Main site entrance road of 2,400 ft^2 surface area and 600 ft^2 of sidewalks, all powered from the local street lighting system
- Drive to the visitor lot of 1,200 ft^2 plus walk of 300 ft^2, powered from the building's system
- Drive to the garage of 1,500 ft^2 plus walk of 450 ft^2, powered from the garage's system
- Drives to each building's loading dock of 800 ft^2 each, plus a dock exterior parking & service lot of 900 ft^2
- Walks interconnecting the buildings and access walks of 1,800 ft^2
- A landscaped area of 12,000 ft^2
- An employee athletic field of 20,000 ft^2
- A canopied entrance to each building of 400 ft^2
- Two exits from each building of 5 lf of double doors each
- Each building is a flat rectangular box 30 ft high, 80 ft deep, and 120 ft long.

What is the exterior lighting allowance?

A

The ELPA for the building facade may be calculated at a maximum area of 36,000 ft^2. The allowance only applies, however, to the facade area actually lit. For example, if only the front of each building is to be floodlighted, then only (30 x 120) = 3,600 ft^2 of each building is used as the basis for the ELPA.

Description	Area or Length	Allowed W/ Unit	Total watts Allowed	Comments
Garage				
Interior spaces	30,000 ft^2	*	*	Interior space: see Sec 6.4 or 6.5, Code
Top level	10,000 ft^2	0.12	1,200	Private lot
Visitor lot	5,000 ft^2	0.18	900	Public lot
Main road	2,400 ft^2	n.a.	n.a.	Exempt: not powered by building
Main road walk	600 ft^2	n.a.	n.a	Exempt: not powered by building
Visitor lot drive	1,200 ft^2	0.15	180	Public road/walk
Visitor lot walk	300 ft^2	0.15	45	Public road/walk
Garage drive	1,500 ft^2	0.10	150	Private road/walk
Garage drive walk	450 ft^2	0.10	45	Private road/walk
Dock drives	800 ft^2	0.10	80	Private road/walk
Dock lots	900 ft^2	0.12	108	Private road/walk
Inter-building walks	1,800 ft^2	0.15	270	Public road/walk
Landscaped area	12,000 ft^2	0.10	1,200	Activity area
Athletic field	20,000 ft^2	n.a.	n.a.	Exempt
Canopied entrances	1,200 ft^2	4.00	4,800	Light traffic
Exits	30 ft	25.00	750	Exit
Building facades	36,000 ft^2	0.25		
Totals			9,728	

determines the area to be used. Even if the canopy is slanted or peaked inside, the measurement is actually of the ground beneath the canopy.

Linear Length of Door Openings. This value is measured in plan view and includes the door opening only; sidelights and other portions of the door which do not open are not part of the linear length.

Area of Building Facades. The intent is to provide a reasonable allowance to light the exterior of buildings for identification, aesthetic and marketability reasons. This area is the sum of all areas of the building exterior intended to be illuminated. Note that many of the surfaces are not in the vertical plane, such as soffits, overhangs, slants and other geometric shapes. Determining the area of these shapes will involve more complex calculations.

Ballasts

There are several basic requirements that apply to fluorescent ballasts, including limits on efficacy, power factor and certain wiring requirements.

Ballast Efficacy

Fluorescent lamp ballasts for F40, F96T12 slimline or F96T12HO lamps must meet or exceed the system efficacy of the "energy saving" or "super low heat" electromagnetic ballast. This requirement applies more to ballast manufacturers than to lighting designers, since these requirements have since been made part of the National Appliance Energy Conservation Act (NAECA). Under this federal law manufacturers must meet the standards for all ballasts brought to the market whether for new buildings or replacements.

Important exemptions from this requirement include:

- Ballasts operating at input power other than 120 or 277 volts AC, 60 Hz
- Low-temperature ballasts
- Dimming ballasts

Tandem Wiring

Two-lamp fluorescent ballasts for the common standard lamps (F40, F96T12 slimline and F96T12HO) are much more efficient than one-lamp ballasts. Use of single-lamp fluorescent ballasts must be minimized as follows:

- Odd lamp-count recessed luminaires (3-lamp luminaires for instance) within 10 ft (center-to-center distance) of one another must be tandem ballast connected if necessary to eliminate the use of single-lamp ballasts.
- Surface mounted or pendant fluorescent luminaires within 1 ft of one another must also be tandem ballast connected if necessary to eliminate the use of single-lamp ballasts.
- Use of three-lamp ballasts is permitted in lieu of tandem ballasting.

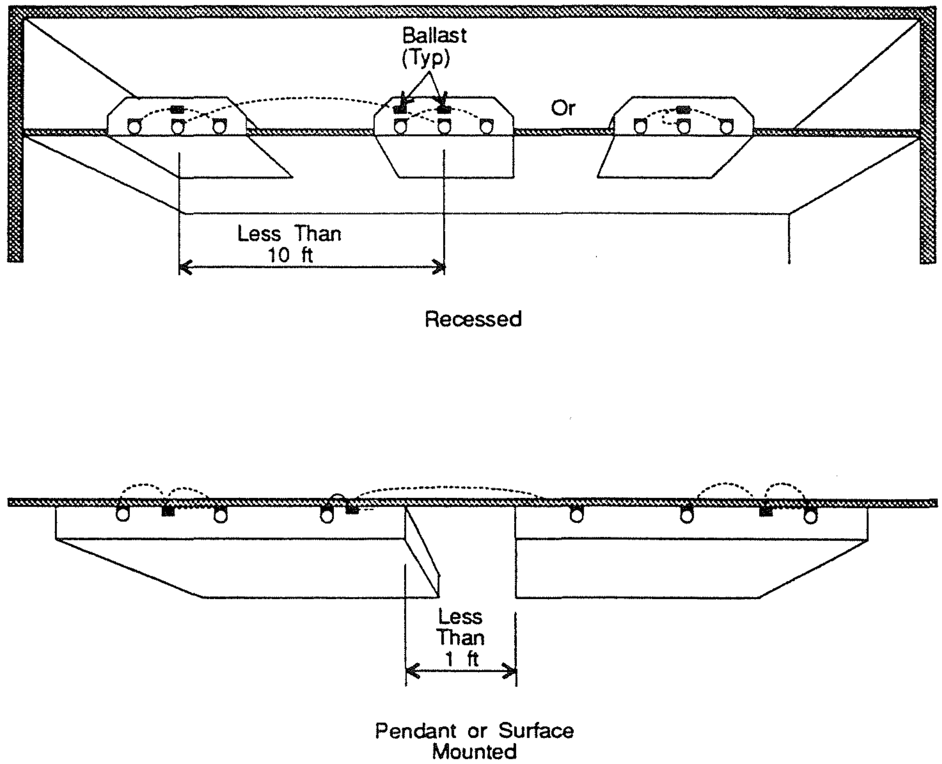
These requirements are illustrated in Figure 2-D. Electronic multilamp ballasts are often a cost effective alternative to tandem wiring.

Power Factor

All ballasts must be *high power factor* (90% or greater), except dimming ballasts, circline fluorescent ballasts, compact fluorescent ballasts and HID lamp ballasts of 100 W or less.

Figure 2-D Tandem Ballasting Requirements

(from ASHRAE Standard 90.1- 1989 User's Manual)



Interior Lighting Power

In addition to the control requirements, compliance for interior lighting is achieved when the connected lighting power (CLP) or the adjusted lighting power (ALP) is less than or equal to the interior lighting power allowance (ILPA). This section identifies the lighting equipment that must be included in the tabulation and that which is exempt. It defines both CLP and ALP and explains how to adjust the lighting power for qualifying automatic lighting controls. It also gives typical wattage values for common lighting equipment.

Adjusted Lighting Power

The adjusted lighting power (ALP) is the connected lighting power (CLP) less any lighting power control credits (LPCC). If credit is not taken for qualifying automatic lighting controls, the ALP is equal to the CLP. The adjusted lighting power is given by the following equation

$$ALP = CLP - LPCC \tag{2-A}$$

where

ALP = the adjusted lighting power of the entire building

CLP = the sum of the connected load power of the circuits or luminaires being controlled

LPCC = the lighting power control credit (discussed later)

The project complies if the ALP is less than the interior lighting power allowance (ILPA) which is calculated by either the prescriptive or system performance methods. In the energy cost budget method of Article 13 of the Code, the ALP is used in the computer model of the proposed design.

Wattages for common lamp and ballast combinations are provided in Tables 2-D and 2-E. These default values are always acceptable in lieu of specific manufacturer's data for lamp, ballast and fixture combinations.

The calculation of ALP and the application of power adjustment factors (PAFs) is described in detail below.

What is Covered in Showing Compliance

Article 6 governs most interior lighting, including both permanent and portable lighting equipment. The following are highlights of some of the more complicated cases:

Covered Parking Garages. Covered parking garages are included in the requirements for interior lighting. Carports, open air parking lots and rooftop parking are included in the requirements for exterior lighting.

Portable Equipment. Although the designer cannot prevent users from plugging-in portable lighting of their own choosing, the designer must account for portable lighting intended for the space, such as systems furniture task lights and lighting in permanent displays. Even if the designer of the project is not responsible for the portable lighting specification, the designer must make a reasonable allowance for such equipment.

Reasonable Lamp Wattages. In the event that a luminaire can accommodate lamps of various wattages, the lamp wattage used for demonstrating compliance must be reasonable for the intended use.

Example 2-P Reasonable Allowances - Edison Based Swag Fixture

Q

If a decorative pendant or "swag" fixture can accommodate 150–watt lamps what should be used for the calculation of the connected lighting power?

A

The answer depends on the lighting design. If 150–watt lamps are intended for proper illumination it is a deliberate misrepresentation to use anything lower. However, if 75–watt lamps are specified and provide proper illumination, then 75–watts can be used for the connected lighting power.

Example 2-Q Reasonable Allowances - Task Lighting

Q

What is a reasonable assumption for determining the connected load for task lighting in an open office plan?

A

The actual task lighting specified for furniture systems should be used when available. Otherwise, a reasonable assumption for an open-office area in which partitions of 48 inches or higher are planned is to allow for one (1) task light per workstation. Unless a specific workstation type and task light is known, an allowance based on a single 40–watt fluorescent task light with energy-saving 1-lamp magnetic ballast (46 W) per 125 ft^2 (100 ft^2 workstation plus 25 ft^2 circulation) can be used.

Example 2-R Exempt Interior and Exterior Lighting - Apartment Building

Q

An apartment building is an adaptive re-use of a former public building. It has four stories above grade and underground parking. There is a statue on the front lawn of an important historic figure, restored during the development of the project. It has a sign in the front exterior as well. Some of the apartments have private patios or balconies. What lighting is exempt?

A

A large portion of the lighting for the project is exempt, including:

- Exit signs, code-required security lights and emergency-only lights
- Lighting in the living units themselves (apartments)
- Exterior lighting for private patios and balconies
- Lighting for the statue ("public monument") and the front sign

However, all other lighting is *not* exempt and is limited by The Hawaii Energy Code. Areas for which calculations are required include the exterior site lighting, the garage, all lobbies, corridors, stairwells and other public areas, common lounges, exercise rooms pools, spas, mechanical rooms, and all other interior and exterior spaces and lighting.

This is particularly applicable to medium (Edison based) fixtures.

Track Lighting. It is especially difficult to determine reasonable allowances for track lighting. The default allowance must be based on one-half of the maximum rated wattage of the luminaire or actual installed lamp wattage, *whichever is larger.* The number of luminaires must be one for every six lineal feet (lf) of track or actual luminaire count, *whichever is larger.*

Exempt Interior Lighting

Article 6 of the Code does not regulate lighting over which the designer has little choice or control. Also exempt is lighting which is required for safety, security or commercial needs. The following are examples of exempt lighting:

Dwelling Units. Private homes of all kinds are exempt from the Code, including apartment buildings three stories and less as well as detached homes and townhouses. However, hotel guest rooms, dormitories and nursing homes are not dwellings and are *not* exempt. In addition, the public (or common) spaces of high-rise apartment buildings are *not* exempt.

Emergency Lights, Exit Signs and Mandatory Safety or Security Lights. If a law or regulation requires lighting for safety or security, then it is generally exempt. It is *not* exempt if it is used as part of non-mandated lighting as well. An emergency egress light is exempt if it is normally off and switched through life-safety controls; however, if the light also serves as a general light source, it is *not* exempt. Typically exempt lighting also includes exit signs, security lights and other lights required by security or safety officials.

Sign Lights. Both self-contained and external illumination for signs are exempt.

Store Window (Exterior-Enclosed) Lighting. However, the store window must not be open to the interior of the store.

Theatrical and Entertainment Lighting. Lighting associated with the specific needs of entertainment, such as disco lighting, film lighting, stage lighting, casino table lighting and similar lighting where specialized lighting equipment and effects are essential for the activity. Note that general architectural lighting in these facilities is *not* exempt.

Specialized Health Care Lighting. Note that the general lighting of medical and dental facilities are *not* exempt; only the examination lights and similar equipment are intended to be exempt.

Gallery or Museum Display Lighting. The varying nature of art display justifies this exemption; however, art galleries primarily for the retail sale of art are retail establishments and are *not* exempt. Ambient lighting in museums is not exempt.

Special Laboratory or Research Lighting. The ordinary general building lighting, including ambient and task lighting, is *not* exempt; only the unique and specific lighting associated with the research is exempt.

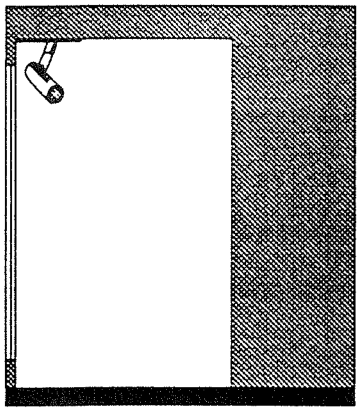
Lighting for Indoor Plant Growth. This exemption is directed at electric lights provided for the needs of interior plants during the hours between 10:00 pm and 6:00 am.

Lighting for the Visually Impaired. The intent of this exemption is to allow the designer as much lighting as necessary to suit these unusual conditions. This exemption is only intended for specific areas of health and elderly care facilities. The key expression is ."*.. spaces primarily designed for use by...*" This literally means, for example, that the bedrooms, corridors, lounges, waiting rooms, dining rooms and other patient-oriented facilities in an elderly-care home are exempt, but the kitchen, examination and treatment rooms and other

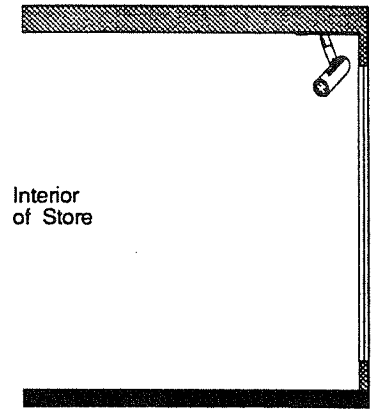
Example 2-S Exempt Interior Lighting - Retail Store Windows

Q

A retail store in a mall has storefront windows on the parking–lot (exterior wall) side and windows on the mall (interior) side. The parking-lot side window displays are closed-off from the store interior, but the displays on the mall side are directly accessible from inside the store. What lighting is exempt?



Window at Parking Side



Window at Mall Side

A

All lighting in the windows on the parking–lot side is exempt; the lighting for the mall–side windows is *not* exempt. However, if the mall-side windows were isolated from the store by any full–height partition, even glass, then they, too would be exempt.

Example 2-T Exempt Interior Lighting - Laboratory Test Lights

Q

A laboratory is studying the effects of lighting on the treatment of a new chemical process. Ordinary fluorescent luminaires are arranged over the test areas and connected to timers. In addition, general lighting is used throughout the laboratory. Is any lighting exempt?

A

The lighting arranged for the test is exempt. However, the lighting should be installed in a manner consistent with the permanence of the experiments; if they are only temporary, then the lighting should not be recessed or otherwise installed in a fairly "permanent" manner.

Example 2-U Exempt Interior Lighting - Retirement Home Cafeteria

Q

A cafeteria in a retirement home is open to the public and visitors. The dining room ordinarily used by the residents of the home is restricted to residents only. Are either of these rooms exempt?

A

The dining room is exempt. However, the cafeteria is exempt only if it serves alternatively as a dining room for residents. If the cafeteria is primarily for visitors and/or staff, it is *not* exempt.

Staff-oriented facilities are *not* exempt. This exemption is *not* intended to apply to offices, retail spaces and other spaces designed primarily for the general public.

Default Wattages

Tables 2-D and 2-E contain default values for lamp-ballast systems. These figures are conservative and may be used in lieu of specific manufacturer's data *for all luminaires.*

Lighting Power Control Credits

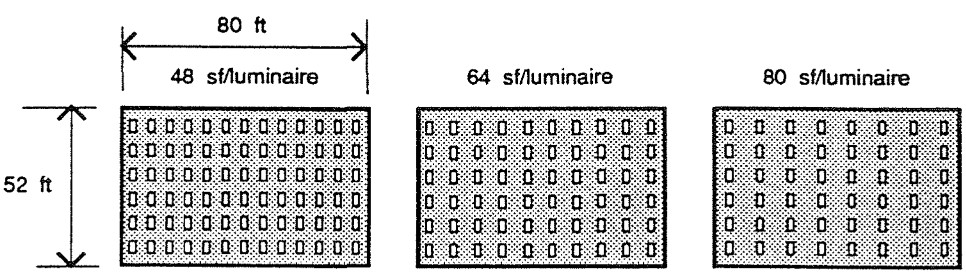
The adjusted lighting power is the connected lighting power less the lighting power control credits (LPCC). The LPCC do not need to be calculated if the project complies without them. The LPCC should be viewed as an option that is available to aide compliance as necessary. The LPCC should be limited to projects which cannot meet compliance directly (the connected lighting power exceeds the interior lighting power allowance).

Figure 2-E Open Plan Lighting Design Examples

(from ASHRAE Standard 90.1- 1989 User's Manual)

The following figure shows a large area measuring 80 feet by 52 feet with common 2x4 fluorescent troffers. The drawings represent typical reflected ceiling plans with luminaires laid out for each 48 ft², 64 ft² and 80 ft². Beneath each layout, several luminaire types along with lamp/ballast choices are indicated. Luminaire types include "lensed", "reflector" and "parabolic". These are listed with two, three and four lamps per luminaire. Two lamp/ballast types are listed: F40ES is a typical T-12 34 watt lamp with an energy efficient electromagnetic ballast (2850 lumens per lamp at 72 watts per pair) T8EB is a typical T-8 32 watt lamp with an electronic ballast (2900 lumens per lamp at 60 watts per pair)

The average maintained illumination level provided by each system along with the associated lighting power density in watts/ft² is shown beneath each lamp layout. These data are provided to give examples of the types of systems that would be required in large areas to satisfy the requirements of the proposed standard.



Luminaire/Lamps	FC	LPD	FC	LPD	FC	LPD
Lensed 2-F40ES	58	1.4	45	1.0	36	0.8
Lensed 2-T8EB	61	1.1	47	0.9	37	0.7
Reflector 2-F40ES	67	1.4	51	1.0	41	0.8
Reflector 2-T8EB	69	1.1	53	0.9	43	0.7
Lensed 3-F40ES	84	2.0	65	1.6	52	1.2
Lensed 3-T8EB	87	1.7	67	1.3	54	1.0
Parabolic 3-F40ES	86	2.0	66	1.6	53	1.2
Parabolic 3-T8EB	90	1.7	69	1.3	56	1.0
Lensed 4-F40ES	108	2.7	83	2.1	66	1.7
Lensed 4-T8EB	112	2.2	86	1.7	69	1.4

Table 2-D Typical Lighting Power for Common Fluorescent Lamp-Ballast Systems

(from ASHRAE Standard 90.1- 1989 User's Manual)

Lamp/Ballast Combination	4 Lamps, 2 Ballasts		4 Lamps, 1 Ballast		3 Lamps, 1 Ballast		2 Lamps, 1 Ballast		3 Lamps, 2 Ballasts		3 Lamps, Tandem-Wired Ballasts	
	ANSI	Enclos-ed	ANSI	Enclos-ed	ANSI	Enclos-ed	ANSI	Enclos-ed	ANSI	Enclos-ed	ANSI	Enclos-ed
Magnetic Energy Saving Ballast												
40–watt F40T12 lamps	176	160					88	80	134	121	129	117
32–watt F32T8 lamps	140	129					70	65	106	98	105	97
31–watt FB31T8 lamps							69	64	105	97	104	96
34–watt F40T12/ES lamps	144	137					72	68	112	107	108	103
40–watt FB40T12 lamps							86	78	134	121	129	117
40–watt F40T5 twin tube lamps							86	90	130	136	129	
Electronic Rapid Start Ballast												
40–watt F40T12 lamps	144	133			117	108	72	67				
34–watt F40T12/ES lamps	120	116			90	87	60	58				
40–watt FB40T12 lamps					100	93	67	62				
Electronic Instant Start Ballast												
32–watt F32T8 lamps			124	111	96	86	63	56				
31–watt FB31T8 lamps					88	79	61	55				
40–watt F40T5 twin-tube lamps					101		71					
Electronic Reduced Output (Low Ballast Factor) Ballast												
40–watt F40T12 lamps					90	81	61	55				
32–watt F32T8 lamps					76	68	51	46				

Table 2-E Typical Lighting Power for Compact Fluorescent Lamps

(from ASHRAE Standard 90.1- 1989 User's Manual)

Lamp Type	Ballast Type	Input Watts
5–watt twin-tube	Reactor preheat	9
7–watt twin-tube	Reactor preheat	11
9–watt twin-tube	Reactor preheat	13
13–watt twin-tube	Reactor preheat	17
9–watt quad-tube	Reactor preheat	13
13–watt quad-tube	Reactor preheat	17
10–watt quad-tube	Autotransformer preheat reactor preheat	16 13
13–watt quad-tube	Autotransformer preheat reactor preheat	18 16
15–watt quad-tube	Reactor preheat	20
18–watt quad-tube	Autotransformer preheat reactor preheat	25 22
18-20–watt twin-tube	370mA preheat or rapid start	22
18–watt twin-tube	270mA rapid-start 265mA electronic IS	23 17
20–watt quad-tube	Reactor preheat	27
24-27–watt twin-tube	340mA rapid-start 265 mA electronic IS	32 21
26–watt quad-tube	Autotransformer preheat reactor preheat	37 31
27–watt quad-tube	Reactor preheat	34
36-39–watt twin-tube	430mA rapid-start 265mA electronic IS	51 26
40–watt twin-tube	40W 265mA rapid-start 265 mA electronic IS	50 36

This subsection explains which types of controls qualify for credits and how the credits are calculated. Hawaii Model Energy Code provides credit for the following classes of lighting controls:

- Daylight sensing (continuous dimming and step)
- Lumen maintenance
- Programmable timers
- Occupant Sensors
- Combinations of the above

For projects that employ these energy conserving lighting controls, the lighting power control credits (LPCC) may be calculated and used as an aide to achieve compliance.

For a given lighting circuit that is controlled by a qualifying control, the LPCC is the connected lighting power for the circuit times a power adjustment factor (PAF) which is associated with the control. The PAFs for all qualifying controls are listed in the Code as Table 6-3 and repeated in this document as Table 2-F. The LPCC is for the entire building, however, and must be calculated as the sum of the credit for each individually controlled circuit. The LPCC is given by the following equation

$$LPCC = \sum_{i=1}^{n} CLP_i \times PAF_i \tag{2-B}$$

where

CLP_i = the connected load power of the circuit or luminaires being controlled

PAF_i = the power adjustment factor from Table 6-3 or Table 2-F below

LPCC = the lighting power control credit

Not all automatic lighting controls are eligible for a credit. The Hawaii Model Energy Code has specific criteria which must be met and specific rules for the application of PAFs. These are summarized as follows:

"The PAF shall be limited to the specific area controlled by the automatic control device." The PAF is only applied to areas and lights actually controlled by the control device (or combination of devices).

Table 2-F Power Adjustment Factors

(Similar to Table 6-3 in the Code)

(from ASHRAE Standard 90.1- 1989 User's Manual)

Automatic Control Type or Combination	With No Daylighting Control	In Combination with the Following Type of Daylighting Control: On/Off	Multiple Step	Continuous Dimming
Daylighting alone	n.a.	0.10	0.20	0.30
Programmable timer	0.15	0.15	0.25	0.35
Occupancy sensor	0.30	0.35	0.35	0.40
Lumen maintenance	0.10	n.a.	n.a.	n.a.
Programmable timer and lumen maintenance	0.15	0.20	0.30	0.40
Occupancy sensor and lumen maintenance	0.35	0.35	0.40	0.45
Occupancy sensor and programmable timing control	0.35	n.a.	n.a.	n.a..

"Only one PAF shall be used for each building space or luminaire..." Note that some PAF values apply to combinations of control devices, such as .40 for occupant sensing with continuous daylighting sensing controls.

"...50% or more of the controlled luminaire shall be within the applicable space." This is especially important when assessing daylit zones and luminaires controlled by daylight sensors. Daylight sensing controls must control all luminaires to which the PAF is applied and that direct a minimum of 50% of their light output into the daylight zone. "Daylighted zone" is defined in Article 3 of the Hawaii Model Energy Code.

"Controls shall be installed in series with the lights and in series with all manual switching devices..." This means that the manual switching device cannot bypass the operation of daylighting sensors, occupant sensors or lumen maintenance sensors. Some lighting control systems, especially those using low-voltage relays, are literally wired in parallel on the low voltage side, but the net effect is a non-bypassing "series" operation as intended.

"When sufficient daylight is available, daylight sensing controls shall be capable of reducing electrical power consumption for lighting (continuously or in steps) to 50% or less of maximum power consumption." Dimming systems typically reduce light output and power to 30% to 40% of maximum, so most will satisfy this criteria if they control all the lighting in the daylighted space. A three level stepped control system (off/50%/100%) will also meet the criteria if the system controls all the lighting in the space.

"Occupancy sensors located in daylighted spaces should be installed in conjunction with a manual ON switch or a photocell override for ON." Where occupant sensors without photocell sensors are installed in daylight zones, the occupant must be able to manually turn the lights on, while the occupancy sensor turns the lights off. This is so that electrical lighting will not be turned on automatically in a space where daylight is available. Where occupant sensors with photocell sensors are installed in daylight zones, the photocell should take precedence in turning the lights on.

Programmable timing controls used for PAF credit shall be capable of programming different schedules for each day of the week, shall have a readily accessible means for temporary override, shall return to schedule after an override and shall maintain time-keeping during a power outage of at least four hours. In most cases, this means the use of modern digital time controllers operating in parallel with a momentary override switch. Latching systems, such as mechanically-held contactors and low voltage relays, are especially appropriate for this application. In some situations, a mechanical 7-day time switch with spring reserve might be allowable if the override is readily accessible.

The values of power adjustment have been determined by a consensus of experts. These values are supported by experience and substantial (although not absolutely conclusive) evidence of relative effect. The values are intentionally conservative, since in actual practice a control device may not perform as advertised or be rendered inoperative by improper installation and adjustment. Of special concern are daylighting and lumen maintenance controls. To work correctly, these systems require sophisticated photoelectric detection, careful calibration, specific locations of detection devices and appropriate control output for the lamp technology employed. The designer should be careful to specify dependable products and to require the commissioning of the system by a trained representative of the control manufacturer.

Example 2-V Calculation of PAF with Combined Controls

Q

The lighting in a perimeter office is connected to a building energy management system (EMS) with a lighting "sweep" control. In addition, the office lights are controlled with a three-step daylight sensing control (ON/50%/OFF). What is the appropriate PAF for the lights in this office?

A

0.25. Item 5 in Table 6-3 is a combined multiple–step daylight sensing control and programmable timing control. This combined system has a PAF of 0.25. Note that multiple–step daylight sensing controls and programmable timing controls have separate PAFs of 0.20 (item 2) and 0.15 (item 12) respectively. These separate values are *not* appropriate for a combined system. The combined values should be applied even if the controllers are not a prepackaged set.

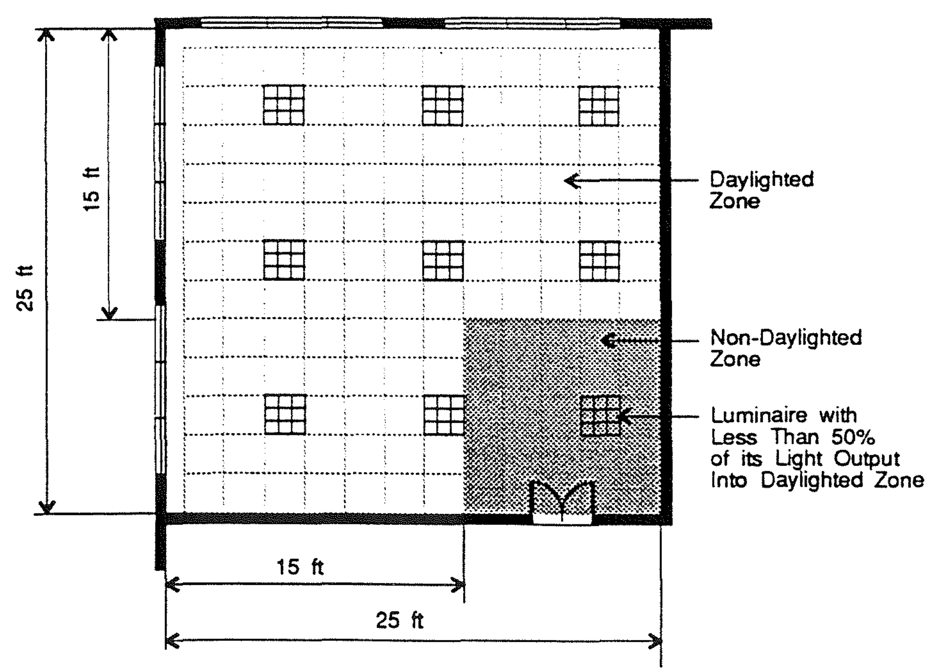
Example 2-W Power Adjustment Factors - Daylight Controls

Q

A room 25 x 25 ft with a 10 ft ceiling has windows along two sides. Fluorescent troffers are installed in the ceiling in a regular pattern (see drawing). A daylight sensing controller is to be used. Which luminaires are controlled?

A

All luminaires except the one well outside of the daylighted zone can be connected to the daylight sensing controller. The one luminaire in the corner is probably going to be needed whether or not adequate daylight is available. Note that this room, at 625 ft^2, will probably need three control points. If the daylighting controller is an automatic continuous dimming type, it meets the three point requirement; a simple on-off switch for the entire room would meet the requirements of 6.3(b). Separate switches for the daylight sensor-controlled lighting and the lone non-controlled luminaire are recommended so that a user can choose to illuminate only the dark corner electrically and not turn on, even at low level, the other luminaires.



Prescriptive Method

This is one of two optional methods for determination of interior lighting power allowance (ILPA). For building types not listed in Table 6-5 of the Code, or for tenant spaces in speculative buildings or projects where space functions are 80% or more defined, the system performance method should be used. The prescriptive method is designed for rapid determination of ILPA and interim testing of a project at the early development of the design.

The prescriptive ILPA is calculated by multiplying the gross lighted area (GLA) times a unit power lighting allowance (ULPA) selected from Table 6-5 of the Code. The ULPA is a watts/ft^2 value based on building type and size.

For building types *significantly different* from those listed in Table 6-5, the prescriptive method may be used as a design guide but the system performance method should be used to demonstrate compliance.

Where applicable, the designer is encouraged to first test compliance using the prescriptive method. If compliance is not achieved, then the system performance method should be used. The system performance method usually provides a more generous lighting allowance.

Prescriptive Method Interior Lighting Power Allowance

The prescriptive unit power lighting allowances (ULPA) in Table 6-5 of the Code are used in calculating interior lighting power allowance (ILPA) as follows:

$$ILPA = ULPA \times GLA \tag{2-C}$$

where

ILPA = the interior lighting power allowance for the entire building

ULPA = the prescriptive unit power lighting allowances (ULPA) from Table 6-5 of the Code. This is based on the GLA and the building type (note two levels of ULPA, the more stringent taking effect in 1993)

GLA = the gross lighted area of the building

If the major occupancy type in mixed-use buildings is 90% or more of the total gross lighted area, then the ULPA for the major occupancy type may be used to calculate the ILPA for the entire building, otherwise, the ILPA is calculated separately for each use and the ILPA for the whole building is the sum of the ILPA for each use.

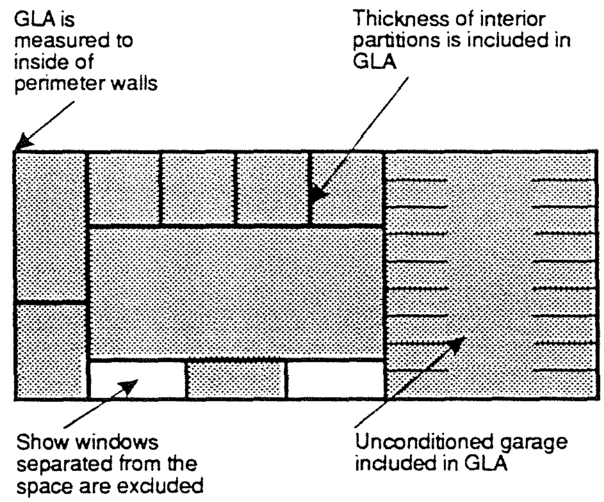
The LTGSTD computer program provided with the Code may be used to calculate the prescriptive ILPA, but the hardest part is determining the gross lighted area and this must be done by hand.

Gross Lighted Area (GLA)

Gross lighted area (GLA) is an important measurement for the prescriptive method: all areas used in this method are GLAs. The gross lighted area of the building is defined as the interior area measured from the inside of the perimeter walls. This area includes the thickness of interior partitions.

In multi-use buildings where the major occupancy is less than 90%, GLA of the *total building* is used to determine the ULPA for each building type or space activity. For instance, a 3,000 ft^2 building with half retail and half office would

Figure 2-F Gross Lighted Area
(from ASHRAE Standard 90.1- 1989 User's Manual)



have a ULPA of 3.08 for the retail and 1.81 for the office, both selected from the column for 4,000 ft^2.

Exempt exterior enclosed store windows are *not* included in the calculation of GLA. For these exempt windows, the GLA is measured from the *interior side* of the enclosed storefront window.

Lighted unconditioned space *is* included in GLA. Examples of this are stairwells, janitor closets, mechanical rooms and unconditioned warehouse spaces.

Covered parking garages are also included in the GLA of the building, even though they are generally not conditioned. When they represent less than 10% of the total GLA, the ULPA for the major occupancy may be used for the garage as well.

Building Type Definitions

The prescriptive method is limited to the few building types listed in Table 6-5 of the Code. These are common building types covering the majority of projects. Where a building type description is directly applicable, it can be applied without further explanation.

Some projects may contain uses or activities that are not specifically listed in Table 6-5, but often a corresponding building type can be found. Where a corresponding building type is used for compliance, a written explanation should accompany the compliance documents. Guidelines for some of these building substitutions are given below:

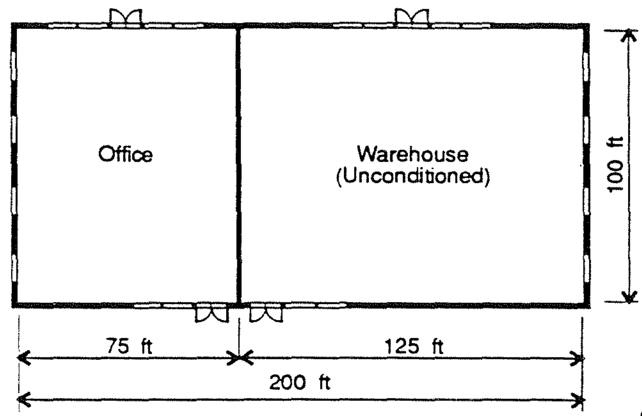
Food Service/Fast Food. This group includes cafeterias, hamburger and sandwich stores, bakeries, ice cream parlors, cookie stores and all other kinds of retail food service establishments in which customers generally are served at a counter and their direct selections are paid for and carried to a table or taken out.

Food Service/Leisure Dining/Bar. This group includes restaurants, cafes, diners, bars, lounges and similar establishments with meals served on a table.

Example 2-X Gross Lighted Area

Q

A one–story building consists of an office and an unconditioned warehouse. The building has 9 in. thick concrete masonry unit walls. The interior dimension of the office is 100 by 75 ft measured from the interior edge of the exterior walls and to the center of the partition wall. The interior dimension of the warehouse is 100 by 125 ft measured from the interior edge of the exterior walls and the center of the partition wall. What is the gross lighted area?



A

Gross lighted area is measured from the inside of the perimeter (exterior) walls and includes the dimensions of all interior walls. The GLA of the building is 200 by 100 ft or 20,000 ft^2. The GLA of the office is 75 by 100 ft or 7,500 ft^2. The GLA of the warehouse is 125 by 100 ft or 12,500 ft^2.

Offices. This group includes all kinds of offices, including corporate and professional offices, office/laboratories, governmental offices and similar facilities. Like all the categories in this table, this is a building-wide allowance which includes offices *and* directly-related facilities, such as conference rooms, lobbies, corridors, toilets, etc. For the purpose of Section 6-4 of the Code, an office building can contain up to 10% (by area) of other uses, such as retail, health club, etc. and still be considered office.

The office category should be used as the basis for buildings or spaces where paperwork and similar activities occur (for instance, libraries).

Retail. A retail store, including department, clothing, dry goods, electronics, toys, accessories and other types of establishments which display objects for direct selection and purchase by consumers. The principal distinguishing element here is the direct selection by the customer, literally removing an item from display and carrying it to the checkout. (Large objects, obviously, are selected and ordered or carried to a customer pickup facility.) Specialty retail food sales, such as cookie and ice cream stores, food sales in connoisseur shops, wine and spirits stores, etc. are considered retail as long as a dining area is not included or is less than 10%. Dining area exceeding 10% of the store total area must be considered separately.

Mall Concourse. This group includes the interior of multifunctional public spaces, such as shopping center malls, airports, resort concourses and malls, entertainment facilities and related types of areas.

Service Establishment. A retail-like facility in which the customer obtains services rather than the direct selection of goods. Retail facilities such as watch repair, real estate offices, auto and tire service facilities, parts departments, travel agencies, etc. are included in this category.

Garages. This category includes all types of parking garages, except for service or repair areas.

Schools. This category includes public and private educational institutions, for children or adults, and may also include community centers, college and university buildings and business educational centers.

Warehouse/Storage. This includes all types of support facilities, such as warehouses, barns, storage buildings, shipping/receiving buildings, boiler or mechanical buildings, electric power buildings and similar buildings where the primary visual tasks are large items.

Multi-Use Buildings

If a building has multiple uses in which a dominant use is less than 90% of the building total gross lighted area, then the ILPA of each use must be calculated independently. For these multi-use projects, the *building total* GLA is still used to select the ULPA for each space.

When a building contains more than one use, the prescriptive ILPA is calculated as the sum of the ILPA for each space activity. This is a modification of the above equation as shown below:

(2-D)

$$ILPA = \sum_{i=1}^{n} ULPA_i \times GLA_i$$

where

ILPA = the interior lighting power allowance for the entire building

$ULPA_i$ = the prescriptive unit power lighting allowances (ULPA) from Table 6-5 for the ith building type

GLA_i = the gross lighted area of the ith building type

For multi-activity buildings, each $ULPA_i$ is based on the entire building gross lighted area, not just the area of the space.

Example 2-Y Prescriptive ILPA - Multi-Use Facility

Q

A multi-use facility consists of 100,000 ft^2 of mall concourse, 250,000 ft^2 of retail lease space, 500,000 ft^2 of office, and 50,000 ft^2 of parking garage, what is the ILPA?

A

The GLA of the project is 900,000 ft^2. The ILPA of the project is 1,055 kW as derived below. The ULPA figures are taken from the greater than 250,000 ft^2 column of Table 6-5 of the Standard for the 1993 level of stringency.

Usage Category		Area (ft^2)	ULPA (W/ft^2)	ILPA (W)
Office		500,000	1.11	555,000
Mall concourse		100,000	0.60	60,000
Retail		250,000	1.72	430,000
Garage		50,000	0.20	10,000
	Totals	900,000		1,055,000

Use of the Prescriptive Method as a Design Tool

The prescriptive method can be used to aid a designer in schematic design and design development phases of a project when final room sizes and/or uses may not be known. By being able to quickly assess the approximate ILPA, the designer can periodically check the ongoing design decisions for probable compliance.

Use of the Prescriptive Method for Speculative Buildings

While the ILPA applies to the whole building, it may be applied to just the core areas, as long as the unit power allotment is based on the entire building area. With speculative buildings, lighting improvements are typically made in phases - First the common areas and then the tenant spaces as they are leased. Each phase of lighting improvements should separately meet the requirements using either the prescriptive or systems performance method.

Use of the Prescriptive Method in Accelerated Construction Projects

Some projects are bid and permitted on the basis of "scope" documents – incomplete designs for which guaranteed maximum prices are contracted. This method allows for heavy construction (site work, foundations, framing, roofing, cladding) to proceed while light construction (interior partitions, etc.) is still being programmed and designed. This procedure compresses building design and construction time.

The designer can use the prescriptive method to determine ILPA for the building type or its closest comparable type. However, the intent of the Code is that the actual ILPA be determined according to the system performance criteria once the actual space design is complete, and if necessary, a revised calculation submitted to the authority having jurisdiction.

System Performance Method

This is one of two optional methods for determination of *Interior Lighting Power Allowance* (ILPA). This method provides greater flexibility and is a more accurate and detailed calculation procedure. While this method requires a greater effort, it is recommended for all building types. Since the system performance method takes into account the space functions and room geometries of the proposed design, it results in a power allowance that is the most appropriate for each project.

The system performance method requires space-by-space calculations which account for the geometry and division of visual tasks within each room. To simplify the use of this approach, the equations and data from the tables have all been incorporated in the LTGSTD computer program (Version 2.1) which is provided with the Hawaii Model Energy Code. *This program is very easy to use*. It can also be a useful tool in early design phases. The application, use and limitations of the LTGSTD program are described in detail later in this chapter.

System Performance Interior Lighting Power Allowance

Unit power density (UPD) allowances are watts per square foot values assigned to specific space functions or activities and are listed in Table 6-6 of the Code. For a given activity type, for example "conference/meeting room", the UPD is multiplied by the area of each meeting room or groups of meeting rooms. This number is also multiplied by the area factor (to account for the room geometry) and the result is a lighting power budget, in watts.

$$LPB = A \times UPD \times AF \tag{2-E}$$

where

LPB = lighting power budget of the space in watts

A = area of the space or group of spaces

UPD = unit power density in watts/ft^2 from Table 6-6 of the Code (note two levels of stringency, the more stringent taking effect in 1993)

AF = area factor adjustment for the room or for the average room from Figure 6-1 or Equation 6-5 of the Code.

For "unlisted spaces," a unit power density of 0.2 W/ft^2 shall be assumed. Unlisted space is defined in Section 3.1 of the Code as "*the difference in area between the gross lighted area and the sum of all listed spaces*". This primarily includes elevators, dumbwaiters, shafts and the cross sectional area of interior walls.

Note that the room or space areas are calculated to exclude inside walls, which differs from the gross lighted area used in the prescriptive method.

The area factor (AF) accounts for the effect of room geometry on illumination systems. In general, rooms with high ceilings relative to floor area require more lighting to illuminate the work plane than rooms with comparatively lower ceilings. This is caused by the absorption of light by the walls above the task, which are larger vertical planes in rooms with high ceilings.

The area factor is determined from Figure 6-1 or Equation 6-5 in the Code. Rooms of identical ceiling height and activity may be evaluated as a group by using the average area of the rooms to determine the area factor.

Regardless of the calculated value, the area factor can be no less than 1.0 and no greater than 1.8. The same limits hold for values from Figure 6-1. The area factor is set to 1.0 for corridors, electrical closets and all indoor athletic spaces (see footnotes in Tables 6-6a, 6-6b and 6-6c).

The LTGSTD Program

The LTGSTD program will aid the designer in determining the exterior lighting power allowance (ELPA), unit lighting power allowance (ULPA) and interior lighting power allowance (ILPA). It contains all of the control point UPD tables and selections of area/activities can be made by scrolling through a list on the screen. It also calculates the area factors and helps to organize the data that are entered and required. LTGSTD does have some limitations, and it is important that the designer consider what the program can and cannot do.

LTGSTD calculates the following:

- Exterior lighting power allowance (ELPA)
- Prescriptive ILPA
- System performance ILPA
- Control points installed
- Control points required

The program does not calculate either the interior or exterior connected lighting power (CLP). Nor does it calculate the interior adjusted lighting power (ALP). These values (including any credits for automatic lighting controls) must be calculated by hand and entered as data into the program. In addition, the program will not recognize the public space exception to the 1,500 W per control requirement.

Since there are two levels of stringency built into the program, the user should be careful to choose the correct year (most likely 1993) for the building under consideration. Otherwise, the designer could be misled by the lighting power allowances displayed by LTGSTD.

The program is extremely useful for keeping track of projects as they develop or change. Each data file can be saved and later modified as required.

The program is also extremely helpful in developing compliance documents. The two-page output provides almost all of the data required for interior and exterior lighting power and control point compliance. Only a worksheet with interior ALP and another with the exterior CLP need to be provided in addition to the program output.

Appendix B of the Hawaii Model Energy Code contains a user's guide for the LTGSTD program.

Organization of the UPD Tables

The unit power density (UPD) tables of the Code are divided into three parts.

- Tables 6-6a applies to *common activities* that may occur in many types of buildings.

Example 2-Z Area Factor - Rectangular Room

Q

A room is 12 ft 6 in. by 10 ft 3 in. from inside wall to inside wall. The ceiling height is 10 ft. What is the Area Factor?

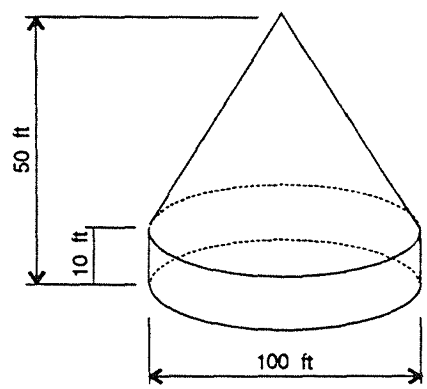
A

The room area is 128 ft^2. The area factor according to Figure 6-1 is about 1.7. Equation 6-5 used in LTGSTD results in an area factor of 1.67.

Example 2-AA Area Factor - Non-Rectangular Room

Q

A circular room has a sloping ceiling rising to a point in the center, much like a sharpened pencil. The diameter of the room is 100 ft. The walls are 10 ft high, and the center of the ceiling is 50 ft. What is the Area Factor?



A

The room area is 7,854 ft^2 as calculated below:

$$A_{ROOM} = \pi \times \left(\frac{100}{2}\right)^2 = 7{,}854\,\text{ft}^2$$

To calculate the area factor, the average ceiling height is used. The average ceiling height is calculated as shown below:

$$H = 50 - \frac{2}{3}(50 - 10) = 23.3$$

According to Figure 6-1, the Area Factor is about 1.13. It may also be calculated with Equation 6-5 as shown below:

$$n = \frac{10.21 \times (23.3 - 2.5)}{\sqrt{7{,}854}} - 1 = 1.40$$

$$AF = 0.2 + 0.8 \times \left(\frac{1}{0.9^{1.40}}\right) = 1.13$$

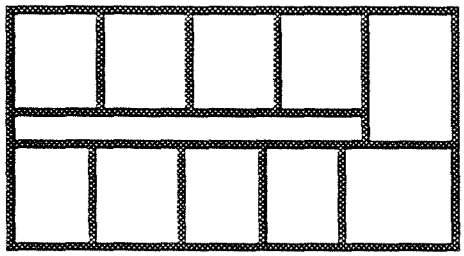
Example 2-BB System Performance ILPA - Office Building

Q

A project consists of the following:

- 10 similar private offices ranging from 10 × 12 ft to 10 × 14 ft in size and totaling 1,350 ft^2 (average size 135 ft^2)
- 150 ft^2 corridor
- 9 ft ceilings

What is the ILPA?



A

As the offices have similar geometry, a single area factor can be calculated and applied to all the rooms.

From Table 6-6a under private offices (Category 1) with reading, typing and filing tasks, the offices are assigned a ULPA of 1.3 W/ft^2. Figure 6-1 gives an area factor of about 1.6 for the average office area of 135 ft^2 and 9 ft ceiling height. However, note "d" limits the area factor for calculation to 1.55. The ULPA for the corridor is 0.8 W/ft^2 and note "b" sets the area factor to 1.0. Using these data, the ILPA is calculated as shown below:

$$n = \frac{10.21(9 - 2.5)}{\sqrt{135}} - 1 = 5.71$$

$$AF = 0.2 + 0.8\left(\frac{1}{0.9^{5.71}}\right) = 1.66$$

$$\begin{aligned} ILPA &= 1{,}350\text{ft}^2 \times 1.3\text{W}/\text{ft}^2 \times 1.55 + \\ &150\text{ft}^2 \times 0.80\text{W}/\text{ft}^2 \times 1.00 = \\ &2{,}840\text{watts} \end{aligned}$$

Example 2-CC Use of the LTGSTD Program - Department Store Building

Q

Lighting plans have been submitted for a 42,750 ft^2 department store building. In addition to the merchandising areas, the building will have private offices, storage areas and other areas of non-sales activities. The interior spaces of the building are described in detail in Example 2-FF. The building is to have three entrances, requiring lighting: (1) a covered, high traffic entry for customers; (2) a smaller side door; and (3) a loading dock. In addition, the designer intends to light a large area on the front of the building. Using the LTGSTD program, will the interior and exterior lighting of this building comply?

A

Yes. The process of compliance is illustrated in the following discussion. The main screen for the LTGSTD program requests the following information.

Example 2-BB Use of the LTGSTD Program - Department Store Building (Continued)

Building Type: Pressing the F6 function key will provide a directory of different building types. These correspond to the prescriptive categories from Table 6-5. A total of three different building types may be combined for a multi-use project. In this case, "D (retail building)" is the appropriate selection.

Building Area: Enter the gross lighted area of the building in ft^2.

Year: Press the F10 function key to choose the appropriate set of lighting power requirements (either 1989 or 1993). This example uses the program's 1989 level of stringency, which is equivalent to the 1991 level listed in Tables 6-5 and 6-6 of the code.

Building Design: Enter total design watts for both interior and exterior lighting power. In this case, the interior adjusted lighting power is 111,900 watts; once this is entered, the program computes the power density value of 2.618 W/ft^2. The exterior connected lighting power is 900 watts.

Prescriptive Criteria: If a value has been entered for building type, the program will now look up the unit lighting power allowance (from Table 6-5), in W/gross ft^2, and compute the total interior lighting power allowance. In this case the design adjusted lighting power is higher than the ILPA allowed by the prescriptive criteria. As such, either redesign the lighting, or perform a system performance criteria test to see if it will achieve compliance.

System Performance Criteria: This measure provides flexible lighting power allowances for different types of building spaces. However, to comply under this criteria, extensive details about all building spaces must be determined. The first step is to get to the space screen and begin entering values. The F5 function key will bring up the space screen.

Number: This column is used to enter room numbers to identify individual spaces in the building. The department store has eight common groups of spaces, which are numbered from 1 to 8.

Type: Pressing the F6 key supplies a list of code numbers that describe the different space types. These descriptions correspond to those listed in Tables 6-6a, 6-6b, and 6-6c of the Code. Each of the descriptions has a code number which are also presented in Table B-2. After entering the appropriate code number for each of the eight different types of space, the program will automatically display a description of each space.

Space Dimensions/Area: Enter the length and width of each space, in ft. These dimensions are from the interior side of the walls at each space. If these values are entered, the program will automatically calculate the area. Alternatively, simply enter the area value directly, as done in the example. For the washrooms (of which there are two) and the offices (of which there are 25), the areas entered are for an individual space *not* the total area of all spaces.

Ceiling Height: The ceiling height, in ft, should be entered here. For sloped ceilings, enter the average ceiling height. Our example building has a constant ceiling height of 9 ft. The program uses this value to calculate the area factor of the space.

Number of Spaces: Enter the number of spaces in the building that are like the one described. In the example, note that there are two washrooms of 250 ft^2, as well as 25 separate office spaces. This number acts as a multiplier, allowing entry of multiple single spaces on one line.

The above values should be entered for each different type of space in the building. Each space will occupy a separate line in the program. The program then computes the values listed below for each space type.

Area Factor (AF): Accounts for effect of room configuration on lighting power utilization.

Unit Power Density (UPD): Refers to the lighting power density for the space in W/ft^2. This value is taken from Tables 6-6a, 6-6b or-6c.

Base Unit Lighting Power Allowance (Pb): Changes the power density to adjust for the area factor; it is equal to the product of the AF and the UPD.

Lighting Power Budget (LPB): Allowed watts for lighting power in each respective space.

Total Lighting Power Budget (LPB): Total allowed lighting power for each of the space types. The program will enter the total of this column under system performance criteria.

In the department store example, use of the system performance criteria has given a higher interior lighting power allowance of 118,808 watts. Since the design interior adjusted lighting power is only 111,900 watts, the interior lighting of the store complies. Compliance is shown on Screen A. Space–by–space lighting power budgets are shown on Screen B.

Example 2-BB Use of the LTGSTD Program - Department Store Building (Continued)

Control Points: The LTGSTD program will also calculate both lighting control points required and equivalent lighting control points installed. Pressing the F5 key from the space screen will access the Controls Data Input Screen. The information that must be entered for each space includes the following: the number of tasks in the space; the type of controls installed; and the number of similar controls installed. The control types are accessed by codes which are presented in Appendix B. Up to two types of controls may be entered for a single space. The space–by–space control point summary is presented on Screen C.

Exterior Lighting: The LTGSTD program will also calculate the exterior lighting compliance. Pressing the F8 key will access the Exterior Data Input Screen. The information requested includes: the exterior area code (from Table B-3) and the length (ft) or area (ft^2) of that type in the project. The program then calculates the allowed watts. The exterior lighting compliance is presented on Screen D.

Screen A – LTGSTD Compliance Summary

```
LIGHTING PRESCRIPTIVE AND SYSTEM PERFORMANCE COMPLIANCE CALCULATION PROGRAM
VERSION 2.1
ASHRAE/IES STANDARD 90.1-1989
ENERGY EFFICIENT DESIGN OF NEW BUILDINGS EXCEPT LOW-RISE RESIDENTIAL BUILDINGS

BUILDING
    DATE

BUILDING TYPE                              AREA
  D Retail                                 42750 ft2
                                     -----------
                                           42750 Gross ft2
BUILDING DESIGN
  Interior Lighting Power        111900 W       2.618 W/Gross ft2
  Exterior Lighting Power           900 W
---------------------------------------------------------------------------

 PRESCRIPTIVE CRITERIA
   Unit Lighting Power Allowance                2.500 W/Gross ft2
   Interior Lighting Power Allowance           106875 W
SYSTEM PERFORMANCE CRITERIA
   Unit Power Density                           2.781 W/Gross ft2
   Interior Lighting Power Allowance           118908 W

 EXTERIOR LIGHTING CRITERIA
   Exterior Lighting Power Allowance              1045 W

****************************************************************************
                                   PASSES
****************************************************************************
                                                                                     TOTAL EQ
```

Screen B -- LTGSTD Space Summary (1 of 2): Interior Lighting Power Allowance

S P A C E NO.	TYPE	DESCRIPTION	SPACE DIMENSIONS	AREA	CLG HT	NO. SPACES	AF	UPD	Pb	LPB	TOTAL LPB
1	101	Type D (Spec		25000	9.0	1	1.00	3.10	3.10	77500	77500
2	102	Type E (Fine		10000	9.0	1	1.00	2.80	2.80	28000	28000
3	105	Tailoring		1000	9.0	1	1.10	2.10	2.31	2306	2306
4	13	Toilet and W		250	9.0	2	1.32	0.80	1.06	264	528
5	45	Bulky Active		1000	9.0	1	1.10	0.30	0.33	329	329
6	46	Fine Active		2000	9.0	1	1.04	1.00	1.04	2084	2084
7	106	Dressing/Fit		750	9.0	1	1.13	1.40	1.58	1186	1186
8	26	Reading, Typ		100	9.0	25	1.55	1.80	2.79	279	6975

Example 2-BB Use of the LTGSTD Program - Department Store Building (Continued)

Screen C – LTGSTD Space Summary (2 of 2): Lighting Control Points

SPACE NO.	SPACE TYPE	SPACE DESCRIPTION	SPACE DIMENSIONS	AREA	CLG HT	NO. SPACES	NO. TASKS	CONTROL TYPE	CONTROL NO.	CONTROL TYPE	CONTROL NO.	CONTROL PTS. INST.	CONTROL PTS. REQD.
1	101	Type D (Spec		25000	9.0	1	2	MANUAL	17	0	0	17	51
2	102	Type E (Fine		10000	9.0	1	2	MANUAL	5	0	0	5	18
3	105	Tailoring		1000	9.0	1	1	MANUAL	2	0	0	2	2
4	13	Toilet and W		250	9.0	2	1	OCCUPANCY	1	MANUAL	1	3	2
5	45	Bulky Active		1000	9.0	1	1	MANUAL	1	OCCUPANCY	1	3	2
6	46	Fine Active		2000	9.0	1	1	MANUAL	1	OCCUPANCY	0	1	2
7	106	Dressing/Fit		750	9.0	1	1	TIMER	1	0	0	2	2
8	26	Reading, Typ		100	9.0	25	1	OCCUPANCY	1	0	0	2	2

Screen D -- LTGSTD Exterior Lighting Power Allowance

EXTERIOR LIGHTING REQUIREMENTS

AREA CODE	AREA DESCRIPTION	AREA OR LENGTH	ALLOWANCE WATTS
3	Entrance (with canopy) High Traffic	60.00 ft^2	600.00
5	Entrance (with canopy) Loading Area	100.00 ft^2	40.00
2	Entrance (without canopy)	6.00 ft	180.00
7	Building Exterior Surfaces/Facades	900.00 ft^2	225.00

• Table 6-6b also gives UPD values for typical space activities which occur in specific building types.

• Table 6-6c applies to *indoor athletic areas*.

Table 6-6c is fairly clear, but the difference between Tables 6-6a and 6-6b is more subtle. The case of a *lobby* may be used to show the difference. Table 6-6a allows 1.0 W/ft^2 for general waiting and reception and 0.8 W/ft^2 for elevator lobbies. These values may be used for all building types. Table 6-6b, however, allows 1.9 W/ft^2 for hotel and conference center lobbies, 1.1 W/ft^2 for post office lobbies and 1.5 W/ft^2 for theater lobbies. These higher values may be used for these specific building types. When the same activities are listed in both Tables 6-6a and 6-6b (as in the case with lobbies), the values in Table 6-6a will always be lower.

The designer can save time by evaluating a lighting design in advance and identifying rooms of the same size, height and use. The calculations can be performed once for each typical room and the LPB for that room may then multiplied times the number of rooms that are like it.

Multifunction Rooms

Rooms with multiple functions requiring supplemental or multiple lighting systems are permitted a 50% increase in lighting power budget (LPB) if:

• The supplementary system is actually installed

• The supplemental lighting system is not greater than 33% of the adjusted LPB for the space

• The supplemental lighting is independently controlled

Simultaneous Activities

If two space/function activities are expected to occur simultaneously in the same room then the weighted average of the two activities' UPD shall be used.

The weighting should be the fairest possible prorating between the two, as follows:

• Absolute activity areas of each activity should be determined.

• The ratio of absolute activity areas of each activity to the total absolute activity area establishes the prorating factor.

• The room's total area is multiplied by the weighted average UPD of the activity using the prorating factor.

Unfinished Areas

The LPB for unfinished areas within a fairly well-defined building may be determined by using the prescriptive unit lighting power allowance from Table 6-5 for space most closely associated with the unknown area. *If this is done, area factors cannot be used.* The calculation is reduced to:

$$LPB = ULPA \times GLA \tag{2-F}$$

This provision is intended as an interim procedure for unfinished spaces, such as an unfinished floor of an office building or school. Once space functions are defined, the power allowance shall be based on the actual space activities.

Example 2-DD Lighting Power Allowance - Multi-Use Hotel Ballroom

Q

A 8,000 ft^2 hotel ballroom with a 16 ft ceiling serves also as a meeting/exhibition room. A fluorescent lighting system (5,200 watts) is used for the meeting and exhibition functions while other lighting (11,000 watts), downlights, chandeliers, and sconces are used for the ballroom function. What is the lighting power allowance for this room?

A

30,240 watts. The lighting power allowance for this room is determined as follows: From Figure 6-1 the area factor of this room is 1.05. From Table 6-6b under "Hotel/Conference Center - Banquet Room/Multipurpose" the UPD is 1.4. The unadjusted lighting power allowance is:

LPB=8,000 × 1.05 × 1.4 = 11,760 watts

An adjustment factor of 1.5 is available for multipurpose rooms 6.5(e)(1). To comply, the fluorescent lighting system must be independently controlled and draw no more power than 33% of the adjusted LPB for the space. The adjusted LPB is:

- $LPB_{adjusted}$ = 11,760 × 1.5 = 17,640 watts
- 0.33 × 17,640 watts =5,821 watts

As the fluorescent lighting is less than 5,821 watts, the adjustment factor may be used.

Example 2-EE Weighted Lighting Power Allowances for Simultaneous Tasks - Architect's Office

Q

An architect's office employs several people in a single room that are engaged in drafting and general office work. The drafting area is 165 ft^2. The office area is 46.5 ft^2. What is the adjusted lighting power allowance for this room at the 1993 level of stringency?

A

The activities are:

- Drafting, office Category 1 (2.2 W/ft^2 limited to AF 1.55)
- Reading, typing, filing, office Category 1 (1.3 W/ft^2 limited to AF 1.55)
- The drafting workstations and surrounds comprise approximately 75% of the total room and the office workstations and surrounds comprise approximately 25%.
- The prorating factor for the drafting task is 0.75
- The prorating factor for the reading task is 0.25
- The UPD is (2.2 W/ft^2 × .75) + (1.3 W/ft^2 × .25) = 1.98 W/ft^2.

Applying the area factor as in the other examples, the power allowance can be determined.

Definitions for Use with the Systems Performance Method (Tables 6-6 (a) (b) and (c))

Use the following rules in applying Tables 6-6a, 6-6b and 6-6c of the Code:

- The more definitive table always takes precedence. For example, use Table 6-6b to determine the ULPA of a hospital corridor since it specifically lists *hospital/nursing home corridor*, rather than Table 6-6a, which simply lists *corridor*.
- In facilities where lists of facility-specific space types are provided (such as Hotel/Conference Center), a general space type occurring in that facility (e.g. an office in a hotel) that is not listed under Table 6-6b but is specifically listed under Table 6-6a, then determine the ULPA from Table 6-6a.
- The definitions of space types are intended to be as specific as possible. For example, *banking activity area* is any area where the activities associated with *banking* take place. The *customer area* is less well defined and in general means those areas where customers stand, sit, wait or move through, as in the lobby. Note that the teller area, the open-plan loan and account offices, the customer counters and similar areas are *banking activities*.
- The use of terms such as active versus "inactive" requires judgment on the part of the designer and authority having jurisdiction. In general, "active" means an area is accessed or used for at least two hours every normal business or use day, whereas "inactive" means rare or occasional access.

Sports definitions in Table 6-6 (c) allow the choice of two or more levels of play quality. Several factors must be considered in selecting values, as follows:

- *Tournament* levels may be selected for any facility which offers or intends to offer tournaments at amateur or professional levels. *Clubs* are intended to mean less organized facilities, such as the community house in a non-sports oriented apartment complex. Generally, the presence of a full- or part-time *pro* in the sport at the facility suggests the intent to offer classes and to arrange tournaments.
- *College* level is associated with the frequent use of the facility for the sport by classes and intramural activity; strictly recreational and intramural activity receives less illumination.
- *Professional* level is associated with the non-televised play of the sport by professional athletes.

The occasional use of a facility by a higher-grade activity generally does not qualify for the higher ULPA.

(1) A local tennis club is *recreational* if classes aren't taught there and *club/college* if classes are. However, even if professional tennis players might be members, only facilities with extensive tennis facilities, including grandstands, are *professional*.

(2) A hockey arena is *amateur* if it is generally rented to the public or available through a department of parks and recreation; however, if regularly scheduled games between high school, college or professional teams are played in the arena, then the higher level is allowed.

Example 2-FF Determination of ILPA - System Performance Method - Department Store

Q

What is the ILPA of the department store which is presented in the table below? All spaces have 9 ft ceilings.

A

118,910 watts are allowed as calculated below. The UPD values are from the Tables 6-6a and 6-6b at the pre-1993 stringency level. The areas and area factors are given. General Apparel is a Type D Retail Establishment. Housewares is a Type E Retail Establishment.

Space	Area (ft^2)	UPD (W/ft^2)	AF	ILPA (W)
General apparel	25,000	3.10	1.00	77,500
Housewares	10,000	2.80	1.00	28,000
Tailoring	1,000	2.10	1.10	2,310
Washrooms (2 at 250 ft^2)	500	0.80	1.32	528
Active storage (bulky)	1,000	0.30	1.10	330
Active storage (fine)	2,000	1.00	1.04	2,080
Dressing/fitting rooms	750	1.40	1.13	1,187
Offices (20 at 125 ft^2)	2,500	1.80	1.55	6,975
Totals	42,750			118,910

Example 2-GG Determination of ILPA - System Performance Method - Tenant Improvement

Q

A tenant takes over a floor in an office building. The net rentable area is 12,280 ft^2; and the ceiling height is 9 ft. What is the ILPA of the project given the data in the table below at the pre-1993 stringency level?

A

The allowed lighting power is 26,005 watts (2.12 W/rentable ft^2). The UPD values are from Tables 6-6a. The areas and area factors are given. 3,750 ft^2 of the office space consists of small enclosed offices (Category 1). 5,570 ft^2 of the office space is open plan, large rooms (Category 2). The UPD for the conference room is increased 1.5 as this room is a multi-use space. The UPD for the coffee/copy room is 1.4 W/ft^2 (kitchen) *not* 2.1 W/ft^2 (office equipment)

Space	Area (ft^2)	UPD (W/ft^2)	AF	ILPA (W)
Office, Category 1	3,750	1.80	1.55	10,463
Office, Category 2	5,570	1.90	1.00	10,583
Conference	670	1.80 x 1.5	1.14	2,062
Corridors	640	0.80	1.00	512
Employee lounge	220	0.70	1.35	208
Lobby	450	1.00	1.20	540
Elevator lobby	350	0.80	1.25	350
Computer room	250	2.10	1.32	693
Coffee/Copy room	300	1.40	1.28	538
Telephone equipment	80	0.70	1.00	56
Totals	12,280			26,005

3. Building Envelope

General Information

Overview of the Chapter

This chapter covers the requirements for walls, windows, roofs and skylights. These envelope requirements apply to most buildings even if they are not air conditioned. Those which are not covered include buildings (or portions of buildings) with permanently open sections of the envelope. Certain other buildings, such as manufacturing or industrial buildings, are exempt from the entire Code as described in Chapter 1.

A summary of requirements for low-rise residential buildings may be found in Appendix A.

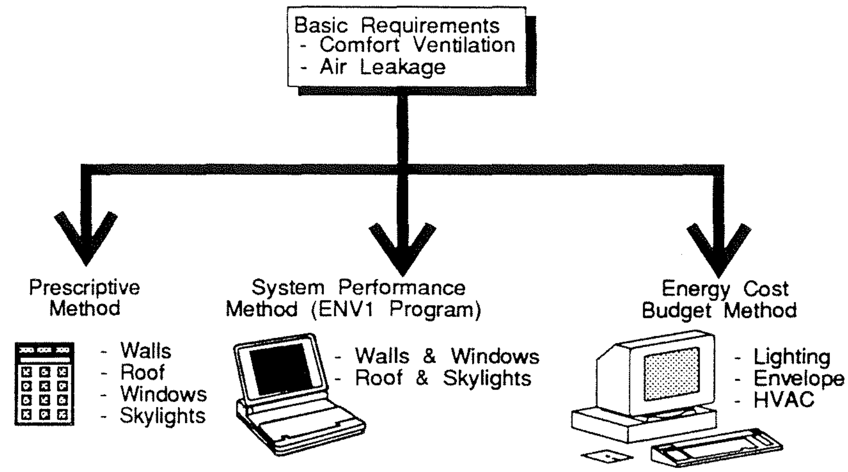
Table 3-A summarizes the building envelope requirements. The basic requirements must be satisfied in all cases. After that, there are three methods to comply with the remaining requirements: the prescriptive, system performance and energy cost budget (ECB) methods.

Under the prescriptive method, the building must meet separate requirements for roof heat gain, wall insulation, window shading and skylight

Table 3-A Summary of the Building Envelope Requirements

Basic Requirements	Apply under all compliance paths	Page
Comfort Ventilation 8.3(e)(1)	Provisions for cross ventilation or ceiling fan ventilation.	3-6
Air Leakage 8.3(e)(2)	Requirements to minimize air leakage in air conditioned buildings	3-7
	AND	
Prescriptive Requirements		
Roof 8.4(a)	Maximum roof heat gain factor (RHGF) limit. Requires insulation, light colors and/or radiant barriers.	3-9
Walls 8.4(b)	Wall insulation requirement for air conditioned buildings. Exception for shaded walls.	3-10
Windows 8.4(c)	Maximum relative solar heat gain (RSHG). Requires window shading or tinted glass in most buildings. Low-rise residential exempt if dwelling is not air conditioned.	3-11
Skylights 8.4(d)	Maximum skylight area limit, depends on skylight shading coefficient. Low-rise residential exempt if dwelling is not air conditioned.	3-13
	OR	
System Performance Requirements		
Walls and Windows 8.5	Computer program allows tradeoffs between wall and window performance based on cooling load equations.	3-15
Roof and Skylights	Program aids in calculation of roof and skylight prescriptive requirements.	
	OR	
Energy Cost Budget Method		
13	If the whole building complies with the code using the energy cost budget method described in Chapter 6, then the prescriptive or system performance requirements do not apply. The basic requirements, however, still apply.	Chpt. 6

Figure 3-A Envelope Compliance Options
(Adapted from ASHRAE Standard 90.1-1989 User's Manual)



area. There is some flexibility to trade off between roof color and ceiling insulation or between window glass type and shading devices.

The system performance method provides more flexibility in the design of walls and windows. A relatively simple computer program allows calculations of tradeoffs between wall and window performance. Although a similar tradeoff is not available for roofs and skylights, the program helps to show compliance with their prescriptive requirements.

If neither of these methods is suitable for a particular building design, then the energy cost budget (ECB) method is available. This method allows trade-offs between building systems. For example, the envelope requirements can be relaxed if a better lighting or HVAC system is installed.

There are a number of instances when neither the prescriptive or system performance methods may be appropriate. The following are examples of trade-offs which would require the use of the ECB method:

- Trade-offs between the exterior wall and roof elements of the envelope
- Trade-offs between the building envelope and lighting energy
- Trade-offs between the building envelope and mechanical systems
- Large skylights or glass roofs typical of atrium spaces

General Considerations in the Design of the Building Envelope

The building envelope uses no energy directly, but its design strongly affects cooling system loads and can reduce the need for electric lighting. Exterior loads include solar gains through windows, conduction due to temperature differences across envelope surfaces, and air leakage (infiltration). The need for electric lighting can be reduced if the envelope is designed to introduce useful daylight into the building.

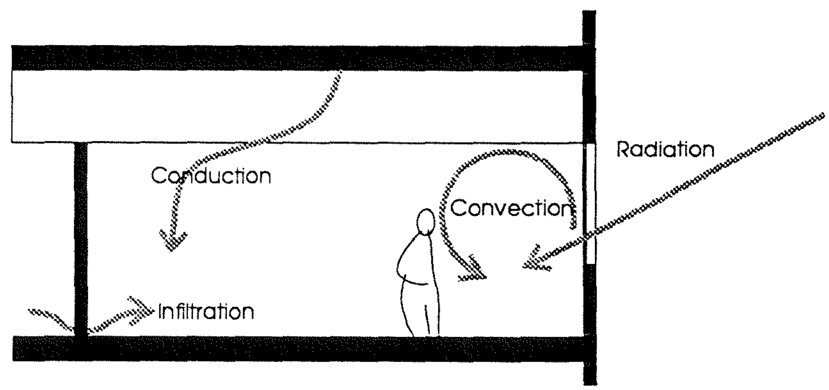
The envelope design can also have a large impact on occupant comfort. Insulated or shaded surfaces will be cooler, making the space more comfortable. In air conditioned buildings, the thermostat may be set slightly higher, saving a significant amount of energy. In some buildings, air conditioning can be avoided completely if the envelope is designed to keep the interior surfaces cool and to allow natural ventilation.

Fenestration is perhaps the most important part of the envelope design. The fenestration design has a significant impact on solar gains and infiltration, and in combination with interior space planning, determines the daylighting potential. Traditionally, fenestration design in warm climates employs dark tints and reflective coatings to control the entry of solar heat. This strategy may still be used to meet the Code. However, recent advances in glazing technology have produced special tints and spectrally selective coatings which block solar heat gain while allowing greater daylight transmission. The designer is encouraged to consider these options to comply with the Code.

In many buildings, especially in one or two story structures, the roof design rivals fenestration in terms of importance. The Code aims to control solar heat gain through the roof by requiring use of insulation, radiant barriers or light-colored roof surfaces.

Figure 3-B External Cooling Loads

(From ASHRAE Standard 90.1-1989 User's Manual)



Example 3-A Refrigerated Warehouse

Q

A refrigerated warehouse in a food processing facility must be maintained at a temperature of 45°F. Do the building envelope requirements apply to this facility?

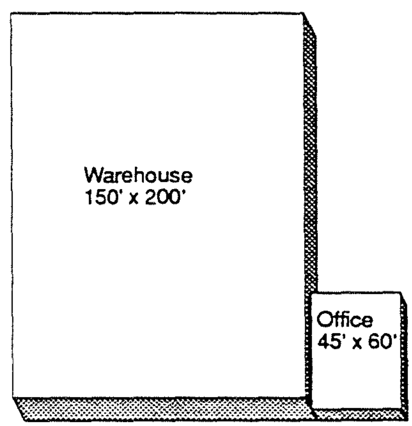
A

No. The envelope standards apply only to *buildings that provide shelter or facilities for human occupancy*. The refrigerated warehouse is considered a process use and the code does not apply. This does not mean that the envelope of the refrigerated warehouse should not be insulated -- quite the contrary. Since the temperature difference between the inside and the outside of the building is much greater in the summer, more insulation than required by the code can easily be justified.

Example 3-B Warehouse

Q

A 30,000 ft^2 warehouse will be used to store household appliances until they are distributed to retail outlets. A 2,700 ft^2 office is attached to the warehouse. The warehouse will not be air conditioned. A single zone cooling system will serve the office area. How do the building envelope standards apply to this facility?



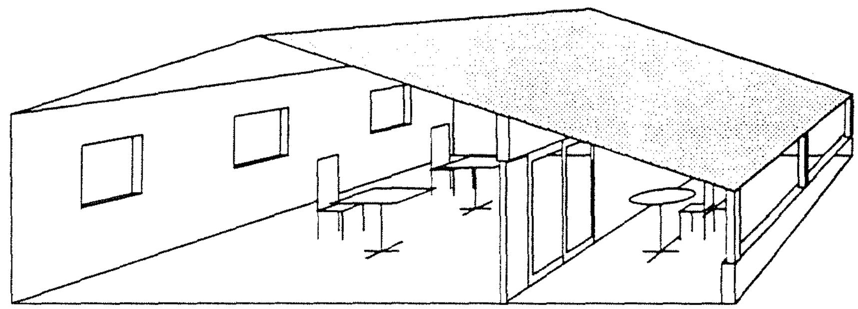
A

The envelope standards apply to the office portion of the building because it is intended for human occupancy. Since the primary purpose of the warehouse section is storage of goods rather than shelter for human occupancy, it does not have to comply unless it is air conditioned for human comfort. Note, however, that the wall dividing the office and warehouse portions must meet the envelope requirements. Since it is shaded, it does not have to be insulated, but it does have to be sealed according to the air leakage requirements.

Example 3-C Restaurant

Q

A beachfront restaurant has an indoor dining area and a covered patio where cocktails are served. The dining area is enclosed by sliding glass doors that are normally open during business hours. The patio is shaded by woven bamboo blinds that are lowered to shield diners from the afternoon sun. How do the building envelope requirements apply to this restaurant?



Dining area must comply Patio area is exempt

A

Since the patio has permanently open sections of wall, it is exempt from the envelope requirements. That means that the walls, roof and windows (if any) that separate the patio from the outdoors do not have to be insulated, shaded or sealed. However, the patio area must still meet other applicable HVAC and lighting requirements. The dining area, on the other hand, has sliding doors that can be closed, and all the envelope requirements apply.

Example 3-D Office Renovation and Addition

Q

The owner of a five-story building plans to renovate the existing offices on the fifth floor and add a sixth floor to create a penthouse office suite. How do the building envelope requirements apply?

A

Since the sixth floor adds to the floorspace of the building, it must comply with the envelope requirements. However, the fifth floor renovation is exempt because it does not add to the existing floor area.

Basic Requirements

This section describes the basic requirements that apply with all compliance approaches. These requirements deal with air leakage and comfort ventilation. Section 8.3 of the Code also contains the eligibility criteria for radiant barriers and the rules and methods for calculating U-values, window shading and roof heat gain. The rules, methods and definitions are included in the Glossary section of this chapter.

Air Leakage and Comfort Ventilation

The code contains basic requirements for limiting air leakage and/or providing comfort ventilation. As with all of the basic requirements, these conditions must be met with all compliance approaches, even the energy cost budget method. Table 3-B shows how these two sets of requirements apply to residential, hotel and commercial buildings. All air conditioned buildings must meet the air leakage requirements, and air conditioned residences must meet the comfort ventilation requirements as well. Buildings which are not air conditioned must comply with the comfort ventilation requirements (although non air conditioned commercial buildings may meet either set of requirements). Note that nothing in the Hawaii Model Energy Code avoids necessary compliance with requirements for fire rated doors and other openings, in fire or building regulations.

Comfort Ventilation

This requirement calls for adequate window openings for cross ventilation or, alternatively, wiring for ceiling fans. The requirement applies to habitable spaces and working spaces (with an exemption for kitchens), which means that it does not apply to areas like hallways, entries, restrooms and storage closets. The requirement consists of the three parts described below. Several exceptions are also listed after the requirements.

- Interior doors must have louvers or have catches to hold them open. This allows air movement through the building. Guest room entry doors in hotels and motels are exempt from this requirement.
- At least two operable openings to the outside must be provided in each space. If a space has only one exterior wall, then the two openings may be placed on either side of a wing wall. Otherwise, the openings must be in opposite or adjacent walls. These openings may include operable windows, sliding glass doors, louvers and entry screen doors (if the entry door is provided

Table 3-B Applicability of the Comfort Ventilation and Air Leakage Requirements

Building Type	Air Cond.	Comfort Ventilation Requirements Apply	Air Leakage Requirements Apply
Residential	Yes	X	X
	No	X	
Hotel or Motel	Yes		X
	No	X	
Commercial	Yes		X
	No	X*	X*

* either set of requirements may be used.

with a door catch to hold it open).

- The minimum operable opening area in each space must be at least 12 percent of the floor area, and no more than 70 percent of the total opening area may be placed on one wall (or on one side of a wing wall). The opening area for a window will usually be smaller than the total rough opening area.

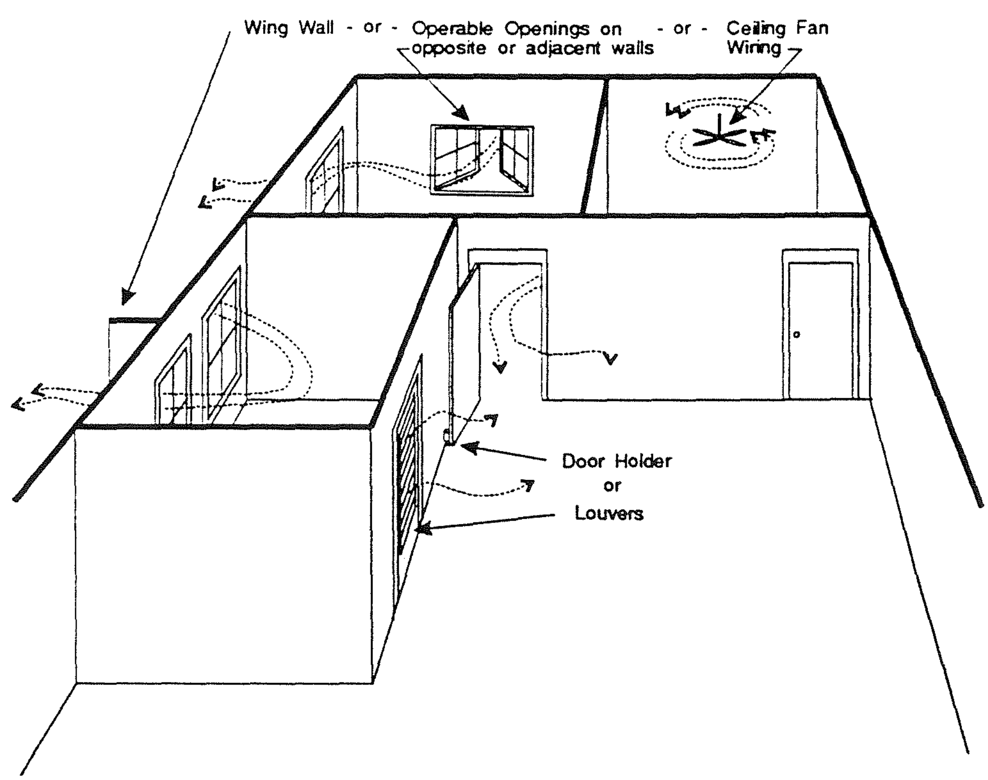
Exceptions. There are three exceptions to the requirements described above. If any of the following conditions applies, then the space does not have to meet the comfort ventilation requirements.

- The first exception applies if a space has at least one ceiling fan outlet for each 400 ft^2 of floor space. If more than one outlet is required, then the outlets must be evenly distributed throughout the room. In addition, the wiring must enable wall mounted fan controls.
- The second exception allows air conditioned guest rooms in hotels and motels to avoid the comfort ventilation requirements.
- The final exception applies to spaces which employ innovative natural ventilation schemes which provide air movement or temperature and humidity conditions for occupant comfort. The concept may be approved based on demonstration or analysis.

Air Leakage

These air leakage requirements apply to all air conditioned spaces. They prohibit the cooling of unclosed spaces (except under certain conditions). They also require tightly closing windows and doors, self-closing or revolving commercial entrance doors and sealing of cracks and holes. A designer might consider meeting these requirements even for an unconditioned building in order to avoid potentially costly upgrades if air conditioning might be added in the

Figure 3-C Comfort Ventilation Requirements



future.

The first requirement states that air conditioned spaces must be enclosed. The space must be separated from the outside by roofs, ceilings, walls, floors, doors and/or windows. If a space has a window or door which is normally open during operating hours, then it is considered unenclosed. Open-air hotel lobbies and restaurants or retail spaces which normally keep their doors open are examples of unenclosed spaces. Such areas may be cooled only under the provisions of Section 9.3(j) of the Code, *Cooling of Unenclosed Spaces* (see Chapter 4).

To meet the second requirement, doors and windows enclosing conditioned space must be weather-stripped or otherwise tightly sealed to minimize air leakage. Openings such as jalousie windows which cannot be tightly sealed are allowed, but they may not account for more than 2 percent of the exterior wall area.

The third part of the air leakage requirement calls for commercial entrances that enclose conditioned space to be self-closing or revolving doors.

Finally, exterior joints, cracks and holes in and between the walls, ceilings and floors which enclose conditioned space must be caulked, gasketed, weather-stripped or otherwise sealed to prevent air leakage.

Prescriptive Method

Overview

Section 8.4 of the code contains the prescriptive criteria for the building envelope. Other envelope compliance options are the system performance (Section 8.5) and the energy cost budget methods (Article 13). The prescriptive option provides the easiest way to comply with the envelope requirements of the Code, but offers limited trade-off possibilities.

These requirements cover the roof, walls, windows and skylights. They apply to all buildings which are covered by the code except as noted below and in the introduction to this chapter.

The Glossary of this chapter addresses concepts such as projection factor, U-value, shading coefficient and heat capacity. These concepts and definitions are common to both the prescriptive method and the system performance method. The Glossary also includes reference information and calculation methods.

Roof

The requirement for opaque roof surfaces is a maximum *roof heat gain factor* (RHGF) of 0.05. The RHGF accounts for three elements of roof design which effect solar heat gain: color, insulation and the presence of a radiant barrier. The calculation of RHGF is described in the glossary to this chapter. Table 3-C lists the maximum allowable roof U-value for several typical roof surfaces. The roof complies with the code if the U-value is less than the value in the table. See Table 3-M in the Glossary for U-values of typical roof constructions.

Note that the *average* RHGF for the whole roof must be less than 0.05. Portions of the roof may fall short of the requirement if other parts have more insulation than is necessary.

Exceptions. A roof is exempt from the RHGF requirement if it is completely shaded from direct sunlight or if the attic is very well ventilated. The minimum attic free area for ventilation for this exception is 1 square foot for each 10 square feet of attic floor area. The calculation of free area for ventilation must account for screens or louvers which reduce the total area of an opening.

Figure 3-D Overview of Prescriptive Envelope Requirements

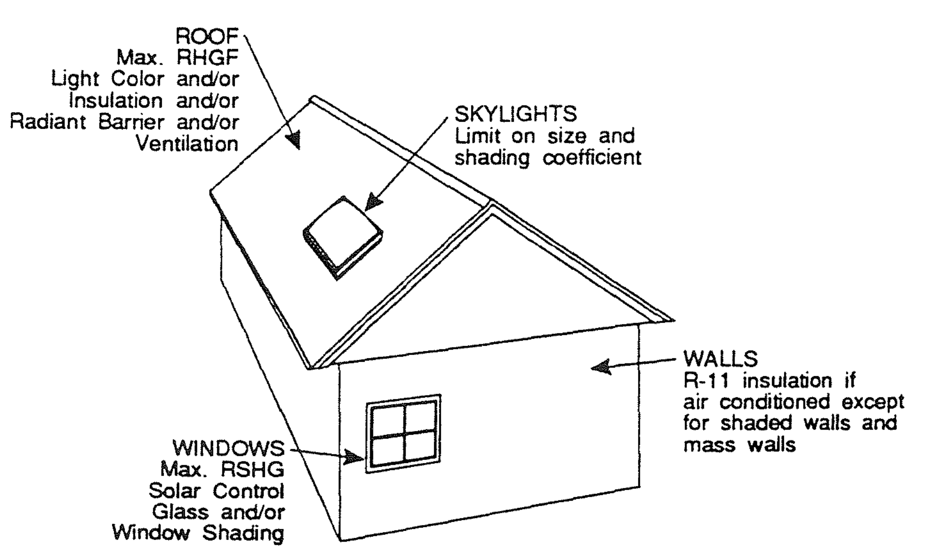


Table 3-C Maximum Allowed Roof U-Value

Roof Surface Color	Absorptivity	Maximum U-Value		Minimum Insulation R-value[1]	
		With Radiant Barrier	Without Radiant Barrier	With Radiant Barrier	Without Radiant Barrier
Black or dark gray	0.90	0.17	0.06	R-3	R-19
Medium Red, Green, Brown, Gray	0.75	0.20	0.07	R-2	R-15
Yellow, Buff	0.60	0.25	0.08	R-1	R-11
Light Gray	0.55	0.28	0.09	R-1	R-8
White (built-up roof)	0.50	0.30	0.10	R-0	R-7
White (tile, paint)	0.40	0.38	0.13	R-0	R-5
White (glazed tile or metal)	0.30	0.51	0.17	R-0	R-3

1 Insulation R-value is based on fiberglass batt insulation in wood framed attics or ceilings. Metal framed roofs will require more insulation.

Walls

Opaque walls must meet a maximum U-value (or minimum insulation R-value) requirement unless the wall meets the conditions for one of the exceptions described below. For wood walls, the maximum U-value is 0.10, and for metal framed walls the limit is 0.15. Guidelines for calculating wall U-values (and lookup tables) are provided in the glossary to this chapter. For any type of wall, R-11 insulation will also satisfy the requirement. An insulation value of R-11 is attainable with about 3½ inches of fiberglass batt insulation or with 2 to 3 inches of foam board insulation. Cellulose or fiberglass blown insulation in a 2x4 framed wall will also meet the requirement.

Exceptions. Walls which do not have to meet the insulation requirement include the following:

- Walls which enclose space which is not air conditioned.
- Walls with a heat capacity (HC) greater than 7.5 Btu/°F·ft² of wall surface area. This includes most, but not all, concrete and concrete block walls (see the glossary). It is always acceptable for compliance to assume that HC is less than 7.5.
- Portions of walls which are completely shaded from direct sunlight all day throughout the year. They may be shaded by building features, adjacent buildings or features of the landscape such as a hill or cliff.
- Portions of walls shaded by overhangs with a projection factor greater than or equal to 0.2 on north-facing walls or 0.3 on all other orientations. The projection factor is illustrated in Figure 3-H in the glossary as the ratio of the horizontal projection of the overhang to the height of the wall (measured as the vertical distance from the bottom of the wall to the bottom outer edge of the overhang). Table 3-D lists the minimum overhang size which allows the wall insulation exception.

Table 3-D Minimum Overhang Size for Exemption from Wall Insulation Requirement (air conditioned buildings only)

Wall Height, ft.	Minimum Overhang Size, in.	
	North	East, South or West
7	17	26
8	20	29
9	22	33
10	24	36
11	27	40
12	29	44
13	32	47
14	34	51
15	36	54

Windows

The purpose of the prescriptive requirements for windows is to limit the amount of solar heat that enters a building. To comply, the windows must not exceed a maximum relative solar heat gain (RSHG) limit. RSHG is a function of the following four features of a fenestration system.

- shading coefficient (SC) of the glass
- type of interior shading device
- type of exterior shading device (e.g. louvers or sunscreens)
- the size of overhangs or sidefins.

The method for calculating RSHG is described in the Glossary to this chapter. Note that in the absence of exterior shades or special interior shades, RSHG is equal to the shading coefficient of the glass. The exceptions to this requirement are described later below.

The maximum RSHG limit depends on the orientation of the windows (north-facing windows have separate criteria) and the size of the windows relative to total wall area (window-wall ratio, WWR). As shown in Figure 3-E, the limit is more stringent for larger windows and less stringent for north-facing windows.

The simplest approach to check for compliance uses Figure 3-F. This method works for unshaded windows or windows with overhangs. These charts show the relationship between shading coefficient, window wall ratio and overhang projection factor (see the Glossary for definitions). If any two of the three factors are known, then the complying value of the third term can be identified on the graph. Note that there are separate graphs for north-facing windows and for east, west or south facing windows. When using these graphs, calculate the WWR separately for the north side, and determine compliance for the north windows separately from the windows on the other three orientations. A wall is considered a north wall if it faces within ±45° of true north.

In many cases a building design includes more than one type of glass or more than one overhang size. It may happen that each individual window condition complies with the requirements as shown in Figure 3-F, but that does not have to be true for the building to comply. If some windows do not have enough shading to comply on their own, the building may still comply as long as the average RSHG is within the limit. To find out, determine the RSHG for each condition and calculate an area-weighted average for the north side and for the combined east, south and west sides. If these two weighted averages are within the limits shown in Figure 3-E, then the building complies. See Example 3-I in the glossary for a sample calculation.

Exceptions. Low-rise residential buildings are exempt from the RSHG requirements if they are not air-conditioned or if are located in a area where

Figure 3-E Window Requirements, Maximum Relative Solar Heat Gain (RSHG)

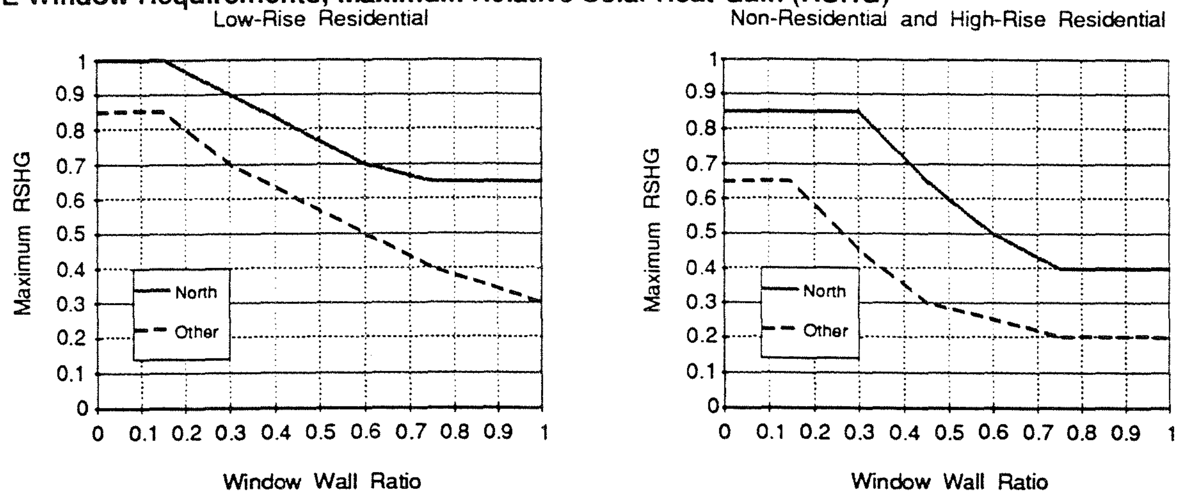
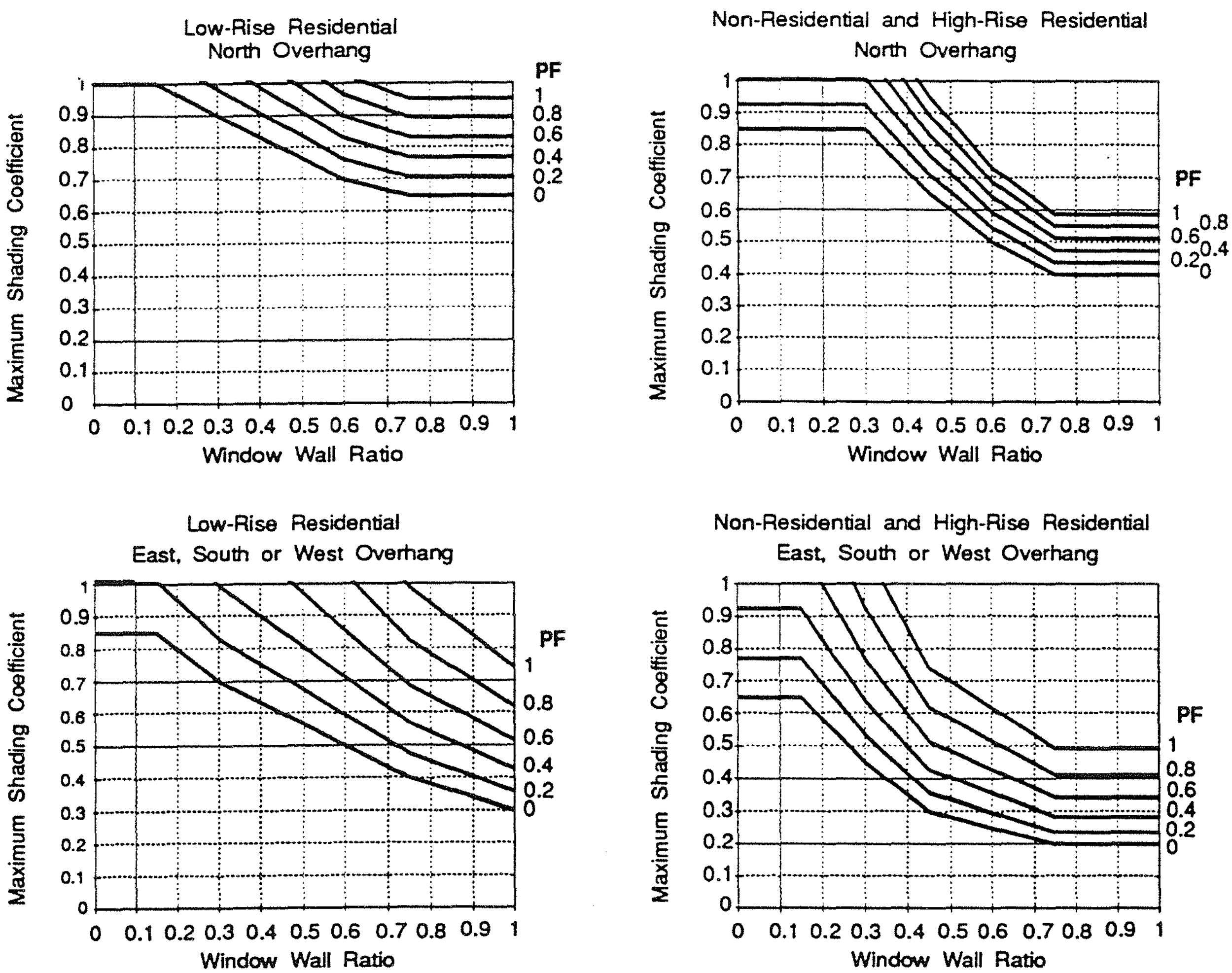


Figure 3-F Illustration of Maximum Allowed Shading Coefficient with Varying Overhang Size



heating is required. Heating locations are defined as those higher than 2,500 feet in elevation or with more than 800 heating degree days (HDD_{65}). See the glossary entry, *heating degree days*, and Table 3-H for a partial list of locations.

A small area of glass, up to two percent of the wall area, on a given orientation may be exempt from the RSHG requirements. This allows small glazed doors and windows to be omitted from the RSHG calculation for convenience.

Skylights

Skylight area is limited to a maximum fraction of the roof area, and the limit depends on the shading coefficient of the skylight material. If a skylight material allows less solar heat to pass through, then the skylight area may be larger. The requirement may be described as a maximum effective aperture, the product of the shading coefficient and the fraction of the roof area covered by skylights. The limit is 0.025 except for non-air conditioned low-rise residential buildings and for those in heating climates (either higher than 2,500 feet in elevation or 800 *heating degree days*) which are both exempt.

Table 3-E may be used for an approximate estimate of maximum skylight area. Otherwise, Example 3-F describes the method for calculating the maximum limit.

Table 3-E Maximum Skylight Area, ft²

Roof Area [a]	Skylight Shading Coefficient								
ft²	0.40	0.50	0.60	0.65	0.70	0.75	0.80	0.90	1.00
700	44	35	29	27	25	23	22	19	18
800	50	40	33	31	29	27	25	22	20
900	56	45	38	35	32	30	28	25	23
1,000	63	50	42	38	36	33	31	28	25
1,100	69	55	46	42	39	37	34	31	28
1,200	75	60	50	46	43	40	38	33	30
1,300	81	65	54	50	46	43	41	36	33
1,400	88	70	58	54	50	47	44	39	35
1,500	94	75	63	58	54	50	47	42	38
1,600	100	80	67	62	57	53	50	44	40
1,700	106	85	71	65	61	57	53	47	43
1,800	113	90	75	69	64	60	56	50	45
1,900	119	95	79	73	68	63	59	53	48
2,000	125	100	83	77	71	67	63	56	50
2,250	141	113	94	87	80	75	70	63	56
2,500	156	125	104	96	89	83	78	69	63
3,000	188	150	125	115	107	100	94	83	75
4,000	250	200	167	154	143	133	125	111	100
5,000	313	250	208	192	179	167	156	139	125
7,500	469	375	313	288	268	250	234	208	188
10,000	625	500	417	385	357	333	313	278	250
20,000	1,250	1,000	833	769	714	667	625	556	500
30,000	1,875	1,500	1,250	1,154	1,071	1,000	938	833	750
50,000	3,125	2,500	2,083	1,923	1,786	1,667	1,563	1,389	1,250
100,000	6,250	5,000	4,167	3,846	3,571	3,333	3,125	2,778	2,500

[a] Roof area and maximum skylight area are listed as horizontal projections. The areas are as they would appear on the building plans.

Example 3-E Roof Insulation for a Supermarket

Q

A supermarket has a metal truss roof construction with a plywood deck and a white gravel built-up roof surface. How much rigid insulation is required on top of the roof deck?

A

From Table 3-C, the maximum allowed U-value for a roof with a white built-up surface ($\alpha = 0.5$) and no radiant barrier (RB = 1.0) is 0.10. Looking in Table 3-M, this metal truss roof can satisfy the requirement using 2.0 in. of expanded polystyrene (U-value = 0.10), 1.5 in. of extruded polystyrene (U-value = 0.10) or 1.5 in. of polyisocyanurate (U-value = 0.078). Alternatively, R-11 fiberglass batt insulation installed beneath the roof deck also complies (U-value = 0.082). Note that these are minimum requirements, and higher levels of insulation may be cost-effective.

Example 3-F Maximum Skylight Area Calculation

Q

A builder of a 1,500 ft² home intends to install medium-white, single-dome skylights that have a shading coefficient of 0.68. How much skylight area is allowed?

A

The maximum allowed skylight effective aperture is 0.025. Rearranging Equation 3-A in the glossary to solve for skylight area:

$$\text{Skylight Area}_{max} = \frac{\text{Effective Aperture}_{max} \times \text{Gross Roof Area}}{\text{SC}}$$

$$= \frac{0.025 \times 1{,}500}{0.68} = 55 \text{ ft}^2 \text{ of skylights}$$

Up to 55 ft² of skylights are allowed. Note that this is the maximum allowed horizontal projection of skylight area; therefore, somewhat more area would be allowed on a sloped roof. For example, if the roof had a standard 18° slope, then:

$$\text{Skylight Area}_{max} = \frac{55 \text{ ft}^2}{\cos(18^\circ)} = \frac{55}{0.95} = 58 \text{ ft}^2$$

Table 3-E is an alternative to the calculations above. A quick look shows that the SC of this skylight falls in the range between 0.65 and 0.70. Therefore, the skylight area limit is between 54 and 58 ft² for a roof area of 1,500 ft². Interpolation will give the exact limit, but if the actual skylight area is less than 54 ft², then no more calculations are necessary.

System Performance Method

Overview

Section 8.5 of the code contains the system performance method. (Other envelope compliance options are the prescriptive and the energy cost budget method options.) For walls and windows, the system performance option offers more flexibility than the prescriptive option and allows one to exceed certain individual baseline requirements, provided that improvements are made in other areas to compensate.

To simplify the use of this approach, the equations have been incorporated into a computer program called ENV1. The program is easy to use and can be a useful tool in early phases of the design as well. For convenience, ENV1 also includes the roof and skylight prescriptive requirements. Therefore, all the envelope requirements, except the air leakage and comfort ventilation requirements, are included in one package.

The system performance method is a convenient compliance path for most buildings except perhaps for low-rise residential buildings which are not air conditioned (because they are exempt from the prescriptive wall and window requirements). The program provides the following benefits:

- It allows tradeoffs on glazing performance between the north side and the other sides.
- The relative solar heat gain (RSHG) and roof heat gain factor (RHGF) are calculated automatically, saving the designer some calculations.
- Credit is given for glazings with a high visible light transmittance (VLT). If two types of glass have the same shading coefficient, then the one with the higher VLT will comply more easily.
- The program produces reports documenting building envelope compliance.
- The user avoids looking up the prescriptive criteria.

Because of the complexity of the system performance equations (for walls and windows), it is recommended that compliance with the Code be shown using the program rather than by hand calculations or attempting to write one's own program. Directions for using ENV1 are in Appendix C.

Figure 3-G ENVI Screen

WALLS INPUT

	Wall Surfaces 1	2	3	4	5	6	7	8
Orientation	N	n	e	E	s	s	w	w
Wall Area	3000	1300	2000	800	3000	1300	2000	800
Glazing Area	720	1170	480	720	720	1170	480	720
SC	0.5	0.72	0.5	0.72	0.5	0.72	0.5	0.72
VLT	0.25	0.5	0.25	0.5	0.25	0.5	0.25	0.5
PF	0	1	0	1	0	1	0	1
Shade OH,SF,N	n	oh	n	OH	N	oh	n	oh
Wall Type M,O	m	o	m	o	m	o	m	o
Uow	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Ins position	2	2	2	2	2	2	2	2
HC	1	1	1	1	1	1	1	1
Shaded? Y,N	n	y	n	y	n	y	n	y
Air-Con? Y,N	n	n	n	n	n	n	n	n

Press ESC or ENTER to view results

Glossary

This section presents definitions, concepts, reference materials and calculation methods.

Index of Terms

This Glossary contains entries for the following terms:

- Absorptivity
- Building Space Definitions
- Building Type Definitions
- Effective Aperture
- Exterior Shade
- Heat Capacity (HC)
- Heating Degree Days (HDD_{65})
- Interior Shades
- Projection Factor (PF)
- Radiant Barrier
- Relative Solar Heat Gain (RSHG)
- Roof Heat Gain Factor (RHGF)
- Shading Coefficient of Exterior Shade (SC_{ext})
- Shading Coefficient of Glass Alone (SC_{glz})
- Surface Definitions
- U-Value
- Visible Light Transmission (VLT)
- Window Wall Ratio (WWR)

Absorptivity

Absorptivity is the fraction of solar radiation absorbed by a unit area of a surface. Values for typical roofing materials are listed in Table 3-F. Data sources include the ASHRAE Handbook 1989 Fundamentals Chapter 3. Absorptivity is a term in the *roof heat gain factor* (RHGF) calculation.

Table 3-F Surface Absorptivity for Typical Roofing Materials

Color (Material)	Absorptivity
Dark, Black (asphalt, black paint or slate)	0.90
Red, Brown, Gray or Green (concrete, rusted metal)	0.75
Yellow, Buff (stone, clay, stucco)	0.60
Light Gray (dull aluminum, galvanized steel)	0.55
White (built-up roof)	0.50
White or light cream (tile, paint, whitewash)	0.40
White (glazed tile or metal)	0.30

sources: ASHRAE Handbook 1989 Fundamentals and DOE2.1 BDL Summary

Building Space Definitions

Habitable space is space in a structure for living, sleeping eating or cooking. Bathrooms, toilet compartments, closets, halls, storage or utility space and similar areas are not considered habitable space.

Working space includes offices, assembly rooms, classrooms, showrooms and similar spaces designed for extended human occupancy. Not included are bathrooms, hallways, storage closets, mechanical rooms, garages and similar spaces as well as portions of warehouses not used for regular human occupancy.

Building Type Definitions

Low-rise residential buildings include multifamily dwelling units of three stories or fewer of habitable space above grade as well as all single and two-family dwellings.

High-rise residential buildings are multi-family dwelling units of four stories or more of habitable space above grade as well as all hotels and motels.

Effective Aperture

Effective aperture is used in this manual to describe skylights. It is the product of the shading coefficient of the skylight and the fraction of roof area covered with skylights.

(3-A)

$$\text{Effective Aperture} = SC \times \frac{\text{Skylight Area}}{\text{Gross Roof Area}}$$

The areas used in the calculation are horizontal projections, as they would appear on a set of drawings in plan view. The shading coefficient for a skylight should be determined from manufacturer's literature. Otherwise, the ASHRAE Handbook 1989 Fundamentals provides guidelines.

Exterior Shade

Permanent exterior shades such as sun screens and louvers may be considered for window shading credit. For louvers the calculation is the same as for overhang and sidefin shading (see *relative solar heat gain*). Automatic or manually operable louvers are assumed to have a *projection factor* of 1.0. For fixed louvers, the projection factor is the ratio of louver width to louver spacing. Horizontal louvers should be calculated as overhangs and vertical louvers as sidefins.

Sunscreens may be woven screens or miniaturized louvers. If possible, use manufacturer's literature to determine the *shading coefficient of exterior shade*, SC_{ext}. The ASHRAE Handbook 1989 Fundamentals, Chapter 27, provides some guidelines for determining the shading coefficient for exterior shade screens.

Heat Capacity (HC)

HC is the heat capacity per square foot of wall area (Btu/ft^2-°F) and is used in the code to quantify the amount of thermal mass in exterior walls. It is used with both the prescriptive and system performance methods. With both methods a benefit is assigned to exterior wall mass that can be traded off against less insulation, and with the system performance method, increased glass area. It is not necessary in all cases to calculate HC; for light weight walls, a default of 1.0 Btu/(ft^2-°F) may be assumed. Table 3-G lists HC for some common concrete and masonry walls.

HC is calculated by using the following equation. The term "i" is an index of each layer in the wall and "n" is the total number of layers that have significant mass.

(3-B)

$$HC = \sum_{i=1}^{n} \text{Density}_i \times \text{SpecificHeat}_i \times \text{Thickness}_i$$

$$\text{Density} = (\text{lb} / \text{ft}^3)$$

$$\text{Specific Heat} = (\text{Btu} / \text{lb}\bullet{}^\circ\text{F})$$

$$\text{Thickness} = (\text{ft}^2)$$

Table 3-G Heat Capacity (HC) for Common Concrete and Masonry Walls (Btu/ft²-°F)

Unit Thickness (inches)	Density (lb./ft³)	Grouting None	Grouting Partial	Grouting Full
		Hollow Concrete Masonry [a]		
6	85	4.8	6.5	9.8
	95	5.4	7.0	10.3
	105	5.9	7.6	10.9
	115	6.4	8.1	11.4
	125	7.0	8.6	11.9
8	85	5.4	8.3	13.9
	95	6.0	8.8	14.5
	105	6.6	9.4	15.1
	115	7.2	10.0	15.7
	125	7.8	10.6	16.3
10	85	7.0	10.5	17.4
	95	7.8	11.2	18.1
	105	8.6	12.0	18.9
	115	9.3	12.8	19.7
	125	10.1	13.6	20.5
12	85	7.7	12.3	21.3
	95	8.6	13.1	22.2
	105	9.4	14.0	23.0
	115	10.3	14.8	23.9
	125	11.2	15.7	24.8
		Hollow Clay Masonry [a]		
4	--	4.7	5.5	7.1
6	--	7.0	8.3	11.1
8	--	9.0	11.0	15.1
		Solid Clay Masonry [a]		
4	--	7.4	--	--
		Heavy Weight Concrete [b]		
2	140	4.7	--	--
4	140	9.3	--	--
6	140	14.0	--	--
8	140	18.7	--	--
10	140	23.3	--	--
12	140	28.0	--	--
		Light Weight Concrete [b]		
2	80	2.7	--	--
4	80	5.3	--	--
6	80	8.0	--	--
8	80	10.7	--	--

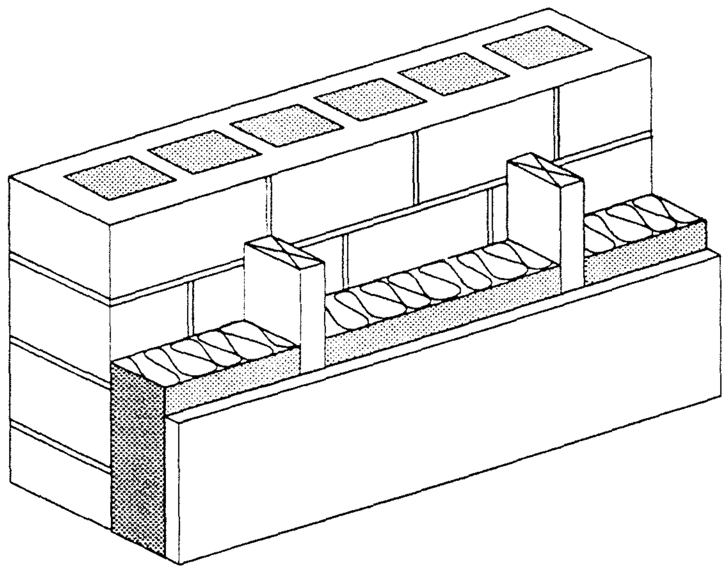
[a] source: *Energy Calculations and Data*, Concrete Masonry Association of California and Nevada, Citrus Heights, CA and Western States Clay Products Association, San Francisco, CA, Oct 1986.

[b] source: ASHRAE Handbook 1989 Fundamentals, Chapter 22.

Example 3-G HC Calculation

Q

What is the heat capacity (HC) for the wall construction depicted below? The exterior wall consists of 8" partially grouted CMU, and the interior has R-11 batt insulation between 2X4 studs (16" o.c.) with an interior layer of 5/8" gypsum board.



A

The HC is the sum of the density times the specific heat times the thickness for each layer of the wall. The calculation can be structured in tabular form as shown below.

Item	Weight (lb/ft^2)	Fraction of Wall	Specific Heat (Btu/lb-°F)	HC (Btu/ft^2-°F)
8" Partially Grouted CMU (105 lb/ft^3)	47.00	1.00	0.20	9.40
2X4 Wood Studs	9.30	0.15	0.33	0.46
R-11 Batt	0.25	0.85	0.30	0.06
5/8" gypsum board	2.60	1.00	0.26	0.68
Total				10.60

Heating Degree Days (HDD_{65})

HDD_{65} is a climate measure used to estimate relative heating energy consumption. For any one day, the degree days are the difference in °F between the mean temperature and 65°F (if the mean is less than 65°F). For example if the 24-hour mean temperature is 57°F on a given day, then the degree days are 65-57=8°F. HDD_{65} as used in the code is the sum of degree days over one year.

In the code, locations with HDD_{65} greater than 800 are considered for certain exceptions. Table 3-H lists HDD_{65} for a number of locations in Hawaii. For a more complete listing see *Climatic Data for Region X Arizona, California, Hawaii, Nevada*, Golden Gate and Southern California Chapters, ASHRAE, Fifth Edition, May 1982.

Table 3-H Locations with greater than 100 Heating Degree Days, base 65°F

Location		HDD_{65}
Kauai	Kokee Air Force Station	979
	Puhi	160
Oahu	Helemano	106
	Kaala Air Force Station	1,709
	Kaena Point	190
	Tantalus	100
Maui	Haleakala Ranger Station	4,272
	Haleakala Summit	6,532
	Kula Sanatorium	789
Hawaii	Hawaii Volcanos National Park	1,712
	Kulani Camp	3,537
	Mauna Loa Observatory	7,670
	Mountain View	177
	Waimea (Kamuela Airport)	826

Source: *Climatic Data for Region X Arizona, California, Hawaii, Nevada*, ASHRAE Golden Gate and Southern California Chapters.

Interior Shades

The benefit of interior shading devices may be calculated using the methods in the ASHRAE Fundamentals Handbook. To assist the designer, data from this and other sources are presented in Table 3-I. This table lists factors that may be multiplied times the shading coefficient of the glass to yield the shading coefficient of the glass in combination with the interior shading device. For instance, if double bronze glass (SC = 0.57) were used with a light colored blind, the adjustment would be 0.80. The combined shading coefficient would then be 0.57 x 0.80 or 0.46.

The benefit of interior shading devices will depend to some extent on the glazing material. A white roller shade, for instance, is more effective with clear glass than with low transmission reflective glass. This is because its effectiveness depends on the ability of the shading device to reflect solar radiation back out the window and this ability is increased with high transmission glass.

Note that when interior shades are used for compliance with the RSHG requirement, the shades might not be able to be removed during future tenant improvements without making other envelope upgrades.

Table 3-I Adjustment for Interior Shading Devices
(From ASHRAE Standard 90.1-1989 User's Manual)

Shading Coefficient of Glass	Light Colored Blind	Medium Colored Blind	Light Colored Drapery	Medium Colored Drapery	Dark Colored Drapery
0.90 - 1.00	0.57	0.67	0.57	0.64	0.73
0.80 - 0.89	0.68	0.75	0.61	0.65	0.76
0.70 - 0.79	0.76	0.81	0.65	0.68	0.77
0.60 - 0.69	0.77	0.82	0.69	0.74	0.81
0.50 - 0.59	0.80	0.84	0.76	0.78	0.85
0.40 - 0.49	0.83	0.85	0.80	0.85	0.93
< 0.40	0.86	0.89	0.83	0.86	0.92

Source: ASHRAE Handbook 1989 Fundamentals and manufacturers' literature.

Projection Factor (PF)

External shading by overhangs and sidefins is credited towards reducing solar gain with both the prescriptive method and the system performance method. The concept of a projection factor (PF) is used to characterize the performance of overhangs and sidefins. For windows, an overhang or sidefin is given credit in the relative solar heat gain (RSHG) calculation. For walls, an overhang with a sufficient PF can exempt a wall from the prescriptive insulation requirements.

Figure 3-H illustrates the three different projection factor definitions. The first, for overhangs over windows, is the ratio of the projection (A) of the overhang from the glazing surface to the height (B) distance from the window sill to the bottom of the overhang. For a sidefin shading a window, the projection (A) is the distance from the surface of the glass to the outer edge of the fin and the width (B) is the distance from the inner edge of the sidefin to the opposite side of the glazing. If the glazing is continuous, then (B) is the distance between sidefins. If two sidefins on either side of a window are different sizes, or if the window is not centered between them, then average the projection factors for the two fins to get a single value for the window. Finally, the projection factor for an overhang that shades a wall is the ratio between the projection (A) of the overhang from the surface of the wall to the height (B) of the wall.

In order for glazing area to qualify as shaded by an overhang, the overhang must extend horizontally beyond the edges of the window a distance at least as great as the overhang projection.

When different overhang conditions exist, it is necessary to calculate a weighted average. The weighting shall be based on the window area shaded.

Note that it is always acceptable to assume that PF equals 0. This is a conservative assumption making it tougher for a building to comply.

Figure 3-H Projection Factor for Overhangs and Sidefins

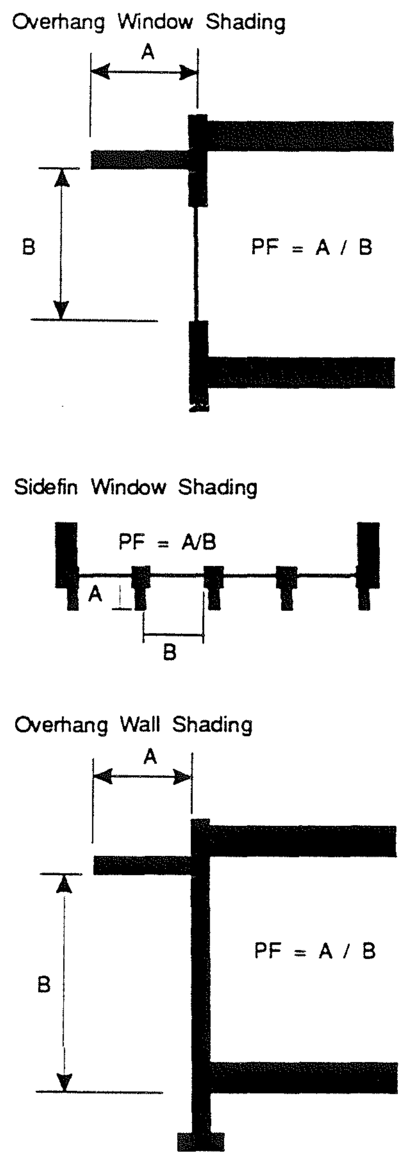
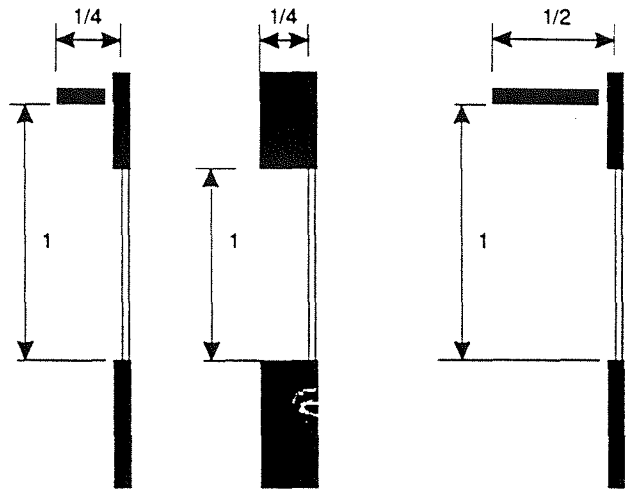


Figure 3-I Examples of Overhang Projection Factors
(From ASHRAE Standard 90.1-1989 User's Manual)



Radiant Barrier

The code allows credit for use of radiant barriers to meet the roof heat gain factor (RHGF) requirement. Radiant barriers are reflective materials that reduce the heat flow through walls or ceilings. In Hawaii they can be installed in an attic or within a roof construction to reduce the amount of solar heat that enters a building. To receive credit for using a radiant barrier, the installation must meet the following criteria.

First, the emissivity of the radiant barrier must be no greater than 0.10. Test data must be available to show that the material meets this requirement, and manufacturer's data is sufficient. Only one side of the barrier needs to meet this requirement.

Second, the barrier must be securely installed using one of 4 methods. These are shown in Figure 3-J and described below.

1. Draped with the shiny side facing down over the top chord of the truss before the roof deck is installed. A minimum air gap of 3/4 inch must be provided between the radiant barrier and the roof deck above at the center of the span. A minimum 3/4 inch air gap must also be provided between the radiant barrier and the ceiling or insulation below.

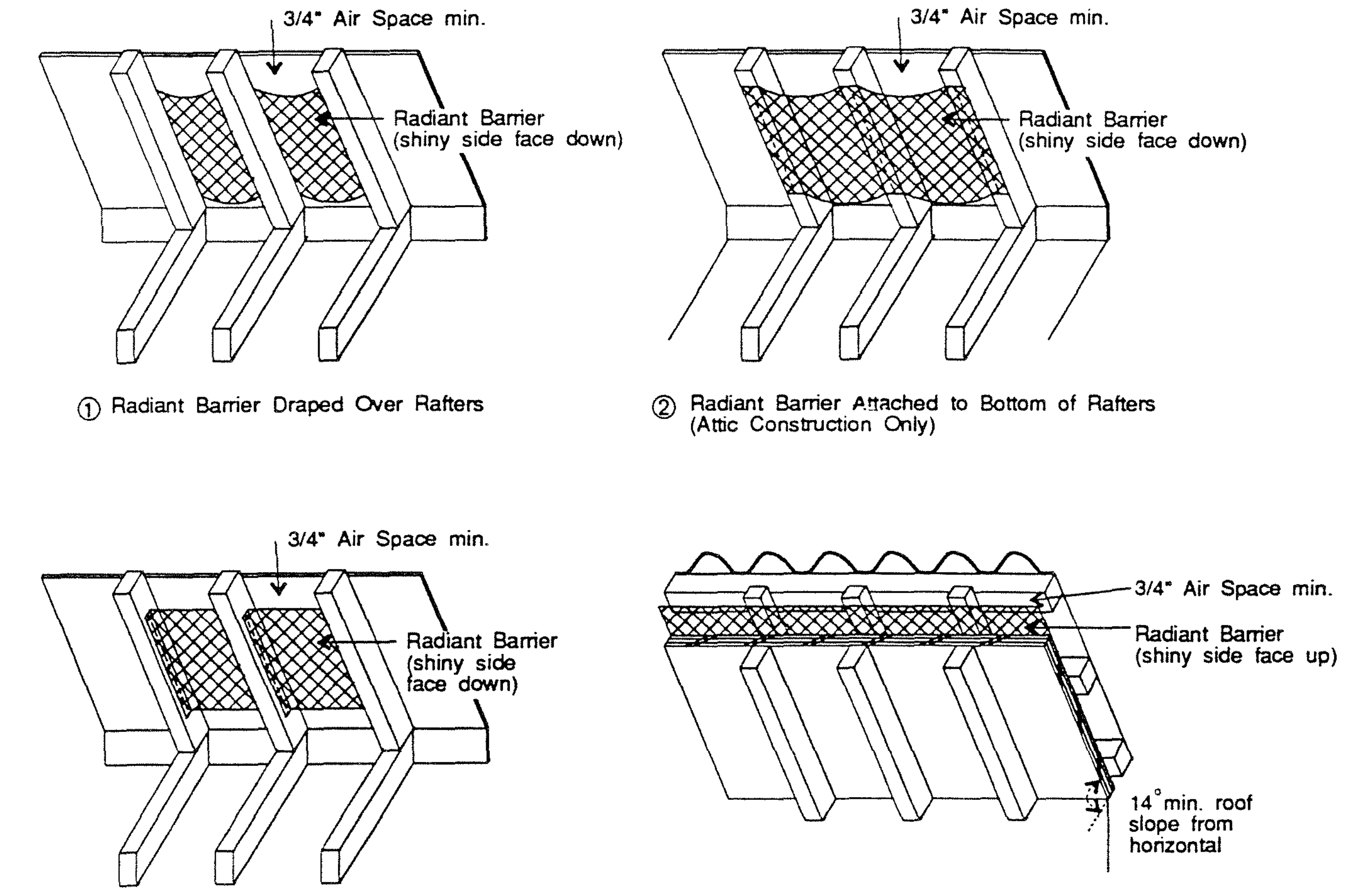
2. Stretched with the shiny side facing down between the top chords of the truss and stapled or otherwise secured at each side. A minimum air space of 3/4 inch above and below is required.

3. Stapled or otherwise secured to the bottom surface of the top chord of the truss and draped below with the shiny side facing down. For attic installations only. A minimum air space of 3/4 inches above and below is required.

4. Laid on top of the roof deck with the shiny side facing up and a minimum 3/4 inch air gap between the radiant barrier and the roofing material above. For open beam ceiling construction only. The roof slope must be greater than or equal to 14° from horizontal.

(Note that the radiant barrier may not be laid on the floor of an attic. Dust on the reflective surface reduces the radiant barrier's effectiveness.)

Figure 3-J Acceptable Radiant Barrier Installation Methods



① Radiant Barrier Draped Over Rafters

② Radiant Barrier Attached to Bottom of Rafters (Attic Construction Only)

③ Radiant Barrier Attached Between Rafters

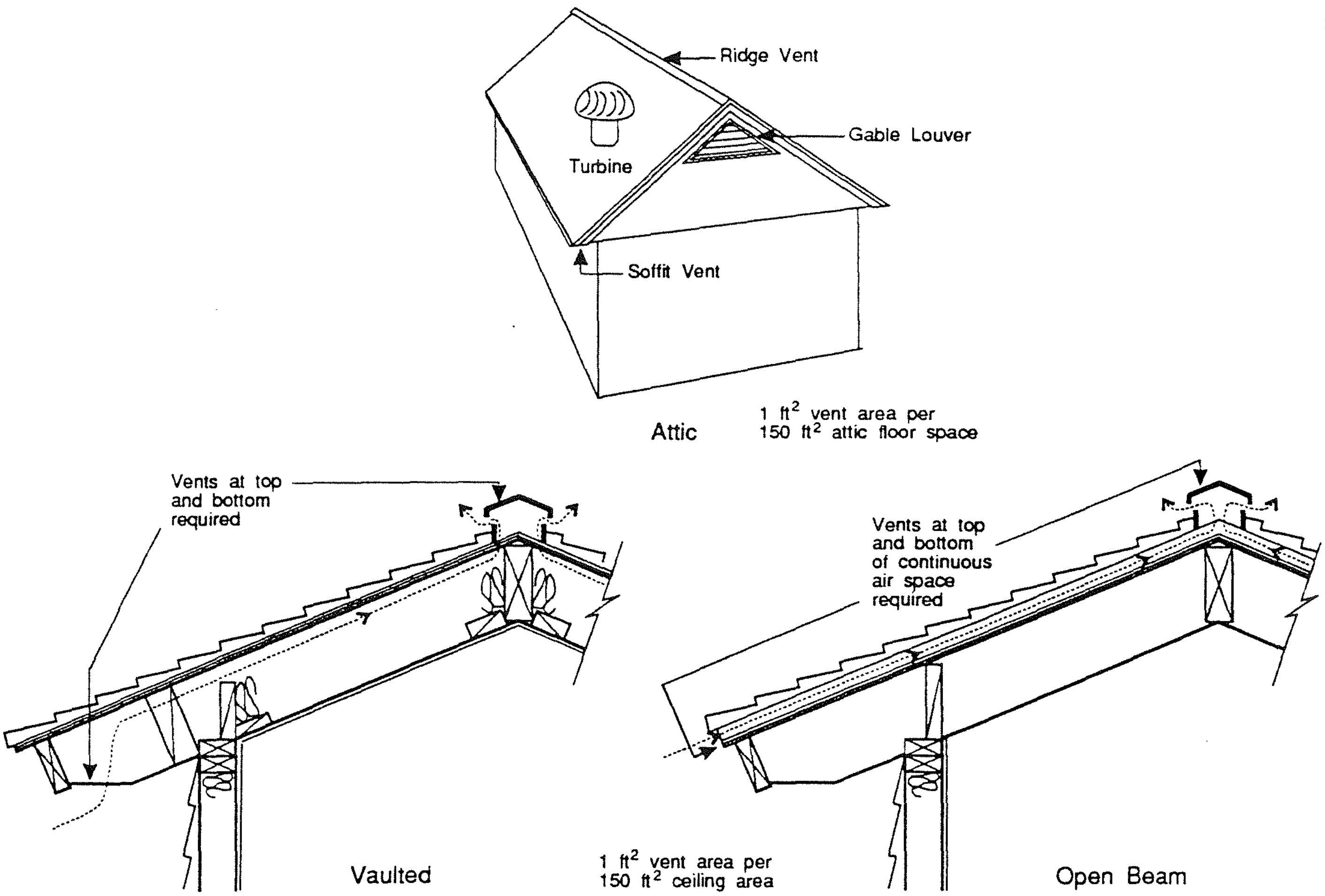
④ Radiant Barrier Laid Top of Roof Deck (Open Beam Ceiling Construction Only)

Finally, In addition to the emissivity and installation requirements listed above, at least one square foot of free area for ventilation must be provided per 150 square feet of attic floor area, or in the case of vaulted or open-beam ceilings, per 150 square feet of ceiling area. In vaulted or open beam ceilings, the air space must be vented with vent area approximately evenly distributed between the top and the bottom. In vaulted ceilings, vents shall be provided for each air space between rafters. See Figure 3-K for examples.

Relative Solar Heat Gain (RSHG)

The window requirements are expressed in terms of maximum relative solar heat gain (RSHG). In the default case, when the fenestration system does not include overhangs, sidefins or exterior shades, and the default interior shade is assumed, then the RSHG is equal to the shading coefficient of the glazing. Otherwise, the RSHG can be calculated with the following equation.

Figure 3-K Required Ventilation for Radiant Barrier Installation



$$RSHG_i = SC_{glz,i} \times \left(\frac{IS_{prop,i}}{IS_{def,i}} \right) \times SC_{ext,i} \times M_i \quad \text{(3-C)}$$

Where:

$RSHG_i$ = Relative solar heat gain.

$SC_{glz,i}$ = Shading coefficient of the glass alone taken from the manufacturer's literature.

IS_{prop} = Interior and/or integral shade shading coefficient adjustment, based on the proposed type of shade and the type of glass (see Table 3-I). Equal to the ratio of the shading coefficient with shades to the shading coefficient of the glazing alone (SC_{glz}). As a default, IS_{prop} may be assumed to equal IS_{def} (then IS_{prop}/IS_{def} = 1.0). (unitless)

IS_{def} = Default shading coefficient adjustment. For a medium-colored venetian blind with the proposed glazing. Equal to the ratio of the shading coefficient of the fenestration with a medium-colored venetian blind to the shading coefficient of the glazing alone. (unitless)

SC_{ext} = Shading coefficient of exterior shade screens or louvers. Default is 1.0 for no shade. May be taken from manufacturer's literature or ASHRAE Handbook 1989 Fundamentals, Chapter 27. (unitless)

M_i = Overhang or sidefin multiplier from the equation below or from Figure 3-L for overhangs or Figure 3-M for sidefins. A value between 0 and 1. Calculated as a function of overhang or sidefin projection factor, *PF*. For a single window, either the overhang multiplier or the sidefin multiplier, but not both, may be used for shading credit.

The overhang and sidefin multipliers are calculated with the following equation.

(3-D)

$$M_i = 1 + a_i \times PF_i + b_i \times PF_i^2$$

Where:

M = Overhang or sidefin multiplier.

PF = Overhang or sidefin Projection Factor. The maximum value allowed

Figure 3-L Overhang Multiplier as a function of Projection Factor

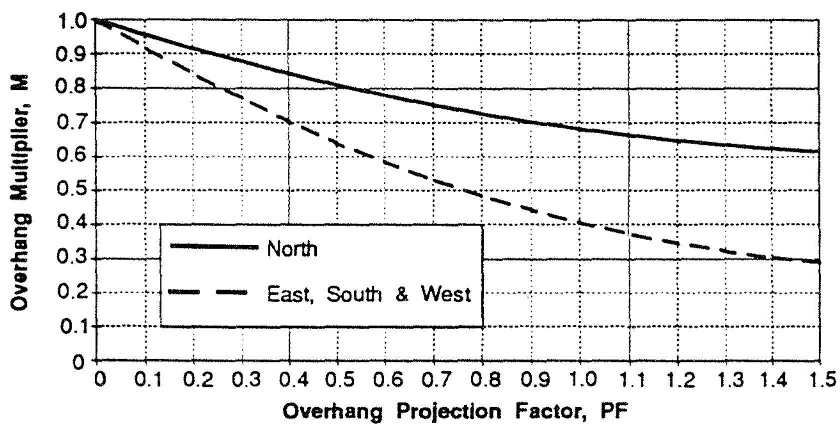
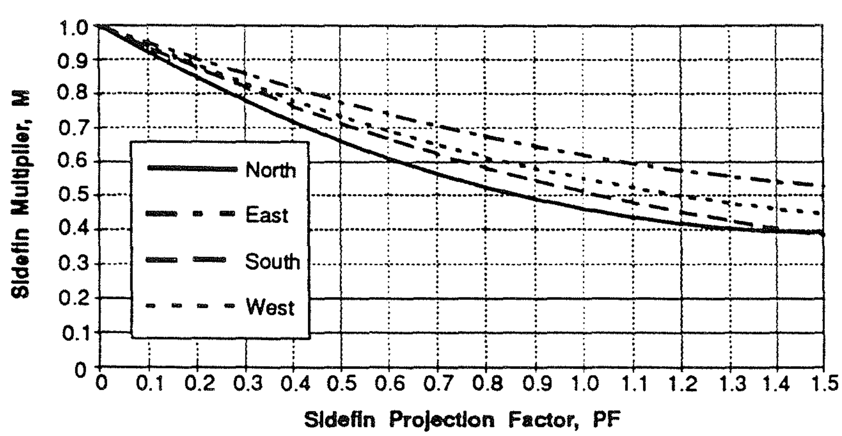


Figure 3-M Sidefin Multiplier as a function of Projection Factor.



for credit is 1.5 . See *projection factor.*

a, b = Coefficients which depend on orientation. See Table 3-J

It may be necessary to calculate an area-weighted average RSHG in cases where some of the windows exceed the maximum RSHG limit. To determine the average RSHG for a set of windows, first calculate the RSHG for each unique window shading condition. Then:

(3-E)

$$RSHG_{avg} = \frac{\sum_{i=1}^{n} RSHG_i \times A_i}{\sum_{i=1}^{n} A_i}$$

where

$RSHG_{avg}$ = the area-weighted average RSHG

$RSHG_i$ = the RSHG of the i^{th} type of window

A_i = glass area of the i^{th} type of window

Table 3-J Overhang and Sidefin Multiplier Coefficients

Orientation	a	b
	Overhang	
North	-0.440	0.123
East, South, West	-0.840	0.245
	Sidefin	
North	-0.81	0.27
East	-0.51	0.13
South	-0.65	0.16
West	-0.61	0.16

Roof Heat Gain Factor (RHGF)

The roof heat gain factor is a product of the roof U-value, the absorptance and a radiant barrier credit. RHGF for a portion of the opaque roof may be calculated with the following equation

(3-F)

$$RHGF = U \times \alpha \times RB$$

U = the U-value of the roof construction. See *U-value.*

α = the absorptivity of the roof surface. See *absorptivity.*

RB = radiant barrier credit. RB equals 0.33 if a radiant barrier is installed or 1.0 if there is no radiant barrier. See *radiant barrier* for installation requirements.

If there is more than one type of roof construction, then determine the RHGF for each portion and take an area weighted average.

Shading Coefficient of exterior shade (SC_{ext})

The shading coefficient of an exterior shade is the ratio of solar heat gain through the shade to the heat gain through clear, double strength glass that is 1/8 inch thick. SC_{ext} is an input to the RSHG calculations. Values may be determined from manufacturer's literature or from ASHRAE Handbook 1989 Fundamentals. The default value is 1.0 if a shade is not used. (see also *exterior shade*).

Example 3-H Calculation of Relative Solar Heat Gain (RSHG)

Q

A five foot high, gray-tinted, 1/4 in. single pane window is shaded by a two foot overhang that is positioned one foot above the top of the glass. What is the RSHG if this is a west-facing window?

A

First, in the absence of the manufacturer's specifications, the shading coefficient of the glass (SC_{glz}) may be estimated as 0.71 from Table 3-K. Then, since no interior shade is specified, the default assumption is that a medium-colored venetian blind will be installed. Therefore, the ratio $IS_{prop.}/IS_{def.}$ equals one. Similarly, because no exterior shade screen is in the plans, SC_{ext} is equal to one. The overhang projection factor as described in Figure 3-H is:

$$\frac{A}{B} = \frac{2}{5+1} = 0.33$$

Therefore, the overhang shading multiplier is (from Equation 3-F):

$$\begin{aligned} M &= 1 + a \times PF + b \times PF^2 \\ &= 1 - 0.840 \times 0.33 + 0.245 \times 0.33^2 = 0.75 \end{aligned}$$

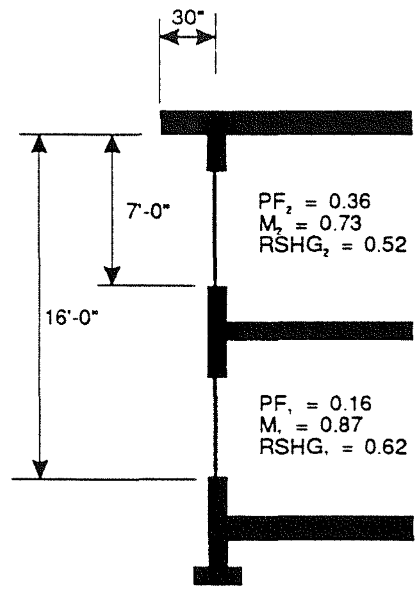
and

$$\begin{aligned} RSHG &= SC_{glz} \times \left(\frac{IS_{prop}}{IS_{def}} \right) \times SC_{ext} \times M \\ &= 0.71 \times 1.0 \times 1.0 \times 0.75 = 0.53 \end{aligned}$$

Example 3-I Weighted Average Relative Solar Heat Gain (RSHG)

Q

The south-facing wall of a two-story office building is shaded with a 30 inch overhang. The green tinted windows have a shading coefficient of 0.71 and cover 240 ft² on each floor. What is the RSHG for these south-facing windows?



A

Since the overhang does not shade the first and second floors equally, it is necessary to calculate an RSHG for each floor and then calculate the weighted average RSHG using Equation 3-E. The projection factor, overhang multiplier and resulting RSHG for both floors are shown in the figure above. They are calculated as shown in the previous example. The weighted average RSHG is:

$$RSHG_{avg} = \frac{(RSHG_1 \times A_1) + (RSHG_2 \times A_2)}{A_1 + A_2} = \frac{0.62 \times 240 + 0.52 \times 240}{240 + 240} = 0.57$$

A check of Figure 3-E, the maximum RSHG chart, shows that these windows will comply if the window wall ratio is less than about 0.20 on the combined south, east and west orientations.

Table 3-K – Typical Shading Coefficients and Visible Light Transmittances
(Adapted from ASHRAE Standard 90.1-1989 User's Manual)

	Uncoated		Low-E [a]		Medium Perf Reflective [b]		High Perf Reflective [b]	
	SC	VLT	SC	VLT	SC	VLT	SC	VLT
Single Glazing (1/8 in.)								
Clear	1.00	0.90	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Bronze	0.85	0.68	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Gray	0.83	0.62	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
High Performance Tint	0.76	0.77	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Single Glazing (1/4 in.)								
Clear	0.95	0.88	n.a.	n.a.	0.65	0.43	0.23	0.08
Bronze	0.71	0.53	n.a.	n.a.	0.52	0.25	0.26	0.05
Gray	0.71	0.45	n.a.	n.a.	0.40	0.13	0.26	0.04
Green	0.71	0.75	n.a.	n.a.	0.50	0.33	0.25	0.07
High Performance Tint	0.58	0.66	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Double Glazing (3/4 in. total thickness, 1/8 in. glass with 1/2 in. air space)								
Clear	0.91	0.82	0.76	0.78	n.a.	n.a.	n.a.	n.a.
Bronze Outer Lite	0.73	0.62	0.59	0.60	n.a.	n.a.	n.a.	n.a.
Double Glazing (1 in. total thickness, 1/4 in. glass with 1/2 in. air space)								
Clear	0.81	0.78	0.72	0.73	0.56	0.41	0.16	0.06
Bronze Outer Lite	0.57	0.47	0.48	0.44	0.40	0.23	0.16	0.05
Gray Outer Lite	0.57	0.41	0.46	0.36	0.40	0.18	0.16	0.04
Green Outer Lite	0.57	0.66	0.49	0.62	0.38	0.30	0.15	0.06
High Performance Tint	0.47	0.64	0.39	0.59	n.a.	n.a.	n.a.	n.a.

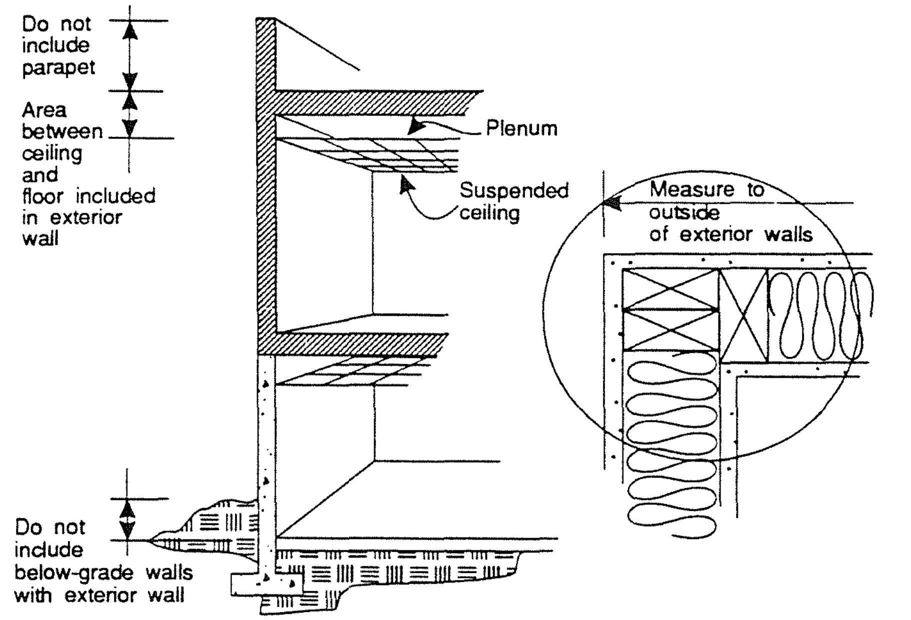
[a] Coating on #3 surface (outer surface of inner pane)
[b] Coating on #2 surface (inner surface of outer pane)

Shading Coefficient of glass alone (SC_{glz})

The shading coefficient is the ratio of solar heat gain through the proposed glass to the heat gain through clear, double strength glass that is 1/8 inch thick. Shading coefficient of the glass is a required input for the prescriptive and system performance requirements.

The shading coefficient may be taken from manufacturer's literature or from tables in the ASHRAE Fundamentals Handbook. It is always allowed to assume a SC of 1.0. Otherwise, typical values are provided in Table 3-K. Single glazing is assumed to be 1/8 or 1/4 inch thick. Double glazing is assumed to consist of either two 1/8 or 1/4 inch panes separated by a 1/2 inch air space. The medium performance reflective coating is typical of "hard" pyrolytic coatings while the high performance reflective coating is typical of "soft" sputtered metallic coatings. Both reflective coatings are assumed to be placed on the inside surface of the glass. The low-e coating is typical of many products on the market, having an emissivity of about 0.15. This coating is assumed to be placed on the outside surface of the inner pane in a double-pane window. It should be noted that double-paned windows are generally not economic in a climate without low outdoor winter temperatures. However, double-pane windows can be useful for their acoustic insulation value.

Figure 3-N Surface Definitions
(Adapted from ASHRAE Standard 90.1-1989 User's Manual)



Surface Definitions

Exterior wall area is measured from the surface of the outside wall. It includes the exterior area between the ceiling of one floor and the floor above (see Figure 3-I)

Fenestration area should generally include the entire glazing area including the frame. For pre manufactured windows, the area is generally the same as the rough frame opening.

U-value

U-value (coefficient of heat transmission) is a measure of the ability of a building envelope to transfer heat; it describes the insulating properties of building envelope components such as walls and roofs. U-value is the inverse of the sum of R-values (Σ R), which are thermal resistance. Σ R includes resistances of surfaces, structural components, and insulation. A lower U-value means lower heat flow through the envelope.

$$U = \frac{1}{\Sigma R} \qquad (3\text{-}G)$$

U-values for typical roof, wall and door constructions are presented here for convenience. For constructions which are not found in these tables, calculation methods are described below. Also included is the method for calculating overall thermal transmittance, an area weighted average U-value for walls or roofs which contain more than one type of construction.

Roof. Table 3-M lists U-values for several typical roof constructions. It includes wood framed roofs (both attic and vaulted) and metal truss roofs. The table lists the roof U-value for several levels of cavity insulation (from none to R-38). The table also includes the U-value for roofs topped with rigid foam insulation varying from 1/2 to 2 inches in thickness. For metal truss roofs, the effective R-value numbers in the table are adjusted to account for the thermal bridging effect of the framing. The constructions are assumed to include a plywood roof deck on top of the framing members and, in the case of the wood frame constructions, a 1/2 inch gypsum board layer below. The single rafter wood frame constructions assume that an air space is allowed for ventilation.

Walls. Table 3-N contains U-values for typical wood framed and metal framed wall constructions. The performance difference between the two framing types is due to the thermal short-circuit provided by metal framing. The effective R-value of cavity insulation in a metal framed wall is about one-half as much as in a wood wall. The table also lists U-values for walls with continuous foam sheathing. U-values are lower for stud spacing at 24 inches rather than 16 inches because the wall contains less framing.

Doors. The opaque wall U-value includes the area-weighted average for all elements of the wall except for the fenestration. Consequently, opaque doors need to be included with the walls. Generally, this will not influence the results much. If doors are glazed, they become part of the fenestration area. In commercial builuings, opaque doors are usually limited to exit doors from stairwells and doors at loading docks. Therefore, for the sake of simplicity, doors may be omitted from the opaque wall U-value calculations if they make up less than about 5 percent of the opaque wall area. The building type which might still have to include the doors in the calculation is a warehouse, particularly one with many loading doors. Tables 3-O and 3-P list U-values for some typical swinging and rolling doors.

Overall Thermal Transmittance. For a wall or roof with more than one type of construction, the overall thermal transmittance is an area weighted average of U-values. This calculation is necessary for cases such as walls with doors or roofs which include both attic and vaulted ceiling constructions.

(3-H)

$$U_o = \frac{\sum_{i=0}^{n} U_i A_i}{A_o}$$

where

U_o =	the U-value of the total area
U_i =	the U-Value of the i^{th} assembly
A_i =	the area of the ith assembly
A_o =	the total area of all assemblies

U-value calculation methods. The code requires that U-value calculations include consideration of all series and parallel heat flows and consider applicable film coefficients (the surface resistance associated with the thin layer of still air on a surface). Three different methods are recommended here, and their use is described in Examples 3-J through 3-L. The methods are different for roofs and walls with metallic framing elements and those with non-metallic framing such as wood or concrete.

- Series or parallel path method -- for constructions with non-metallic framing.
- Effective R-value method -- for metal framed walls.
- Zone method -- an alternative to the effective R-value method.

The series or parallel path method is the classic approach to calculating the thermal transmittance (U-value) for construction assemblies (see example 3-J). The thermal transmittance through each unique portion of the construction assembly is calculated separately. The overall thermal transmittance is then calculated as the weighted average. This method can be used with construction assemblies that have non-metallic framing members such as wood or concrete.

The effective R-value method accounts for thermal bridging due to metal framing. The effective R-value of the cavity insulation is adjusted for the effect of the framing. The effective R-values are listed in Table 3-M for metal trusses surrounded by insulation and in Table 3-N for metal stud walls (see Example 3-K).

The zone method may be used as an alternative to the parallel path correction factor method when the conditions of that method do not apply. The zone method is intended for constructions with metal bridging elements. See Example 3-L.

Insulation which is compressed must be derated in accordance with Table 3-Q or the reduction may be calculated in accordance with the procedures in the ASHRAE Fundamentals Handbook.

Calculations using information from *"Catalog of Thermal Bridges in Commercial and Multifamily Residential Construction"* published by Oak Ridge National Laboratory, Oak Ridge, TN 37831 (ORNL/Sub/83-SA407/1), December 1989 are also acceptable. This publication provides a list of typical thermal bridges and offers examples of better construction practices which will improve energy performance.

Table 3-L Calculation Methods for Wall and Roof Construction Assemblies

(Adapted from ASHRAE Standard 90.1-1989 User's Manual)

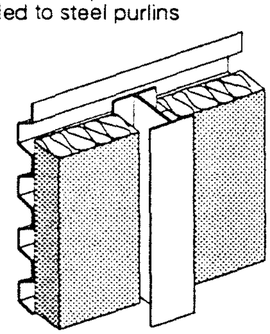
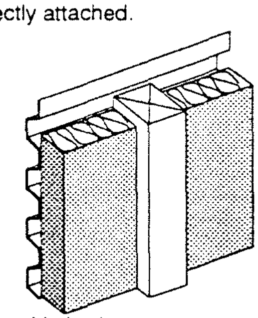
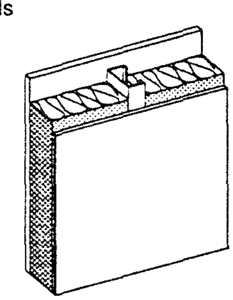
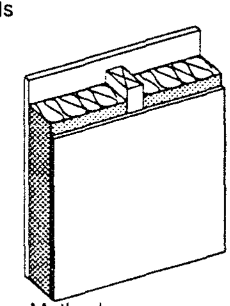
	Metal Framing	Non-Metal Framing
Metal Sheathing	Typical Example: metal deck welded to steel purlins 	Typical Example: concrete structural frame with metal siding directly attached. 
	Acceptable Calculation Methods	
	Thermal Bridges in Sheet Metal Construction	Series or Parallel Path
Non-Metal Sheathing	Typical Example: metal stud walls 	Typical Example: wood framed walls 
	Acceptable Calculation Methods	
	Effective R-Value Zone Method	Series or Parallel Path

Table 3-M Typical U-Values for Roofs -- Attics, Single-Rafter (Vaulted) and Metal Truss Constructions (Btu/h-ft^2-°F)

(Adapted from ASHRAE Standard 90.1-1989 User's Manual)

Nominal	Effective	U-value	Expanded Polystyrene			Extruded Polystyrene				Polyisocyanurate				
Insul.	Insul.		1.0"	1.5"	2.0"	0.75	1.0"	1.5"	2.0"	0.5"	0.75	1.0"	1.5"	2.0"
R-value	R-value		R3.8	R5.7	R7.6	R3.7	R5.0	R7.5	R10.0	R3.6	R5.4	R7.2	R10.8	R14.4
Wood Framed Attic (3.5 inch bottom chord)														
None	(0.0)	0.287	0.137	0.109	0.090	0.139	0.118	0.091	0.074	0.141	0.112	0.094	0.070	0.056
R-11	(11.0)	0.073	0.057	0.051	0.047	0.057	0.053	0.047	0.042	0.058	0.052	0.048	0.041	0.036
R-19	(18.0)	0.048	0.040	0.038	0.035	0.041	0.039	0.035	0.032	0.041	0.038	0.036	0.032	0.028
R-30	(30.0)	0.032	0.029	0.027	0.026	0.029	0.028	0.026	0.024	0.029	0.028	0.026	0.024	0.022
R-38	(38.0)	0.026	0.024	0.023	0.022	0.024	0.023	0.022	0.021	0.024	0.023	0.022	0.020	0.019
Single Rafter Wood Joists (5.5" depth)														
None	(0.0)	0.262	0.131	0.105	0.088	0.133	0.114	0.088	0.072	0.135	0.109	0.091	0.068	0.055
R-11	(11.0)	0.072	0.056	0.051	0.046	0.057	0.053	0.047	0.042	0.057	0.052	0.047	0.040	0.035
R-13	(13.0)	0.063	0.051	0.046	0.043	0.051	0.048	0.043	0.039	0.051	0.047	0.043	0.038	0.033
R-15	(15.0)	0.053	0.044	0.041	0.038	0.044	0.042	0.038	0.035	0.045	0.041	0.038	0.034	0.030
Single Rafter Wood Joists (7.25" depth)														
R-19	(18.0)	0.048	0.040	0.037	0.035	0.040	0.038	0.035	0.032	0.041	0.038	0.035	0.031	0.028
R-21	(21.0)	0.043	0.037	0.034	0.032	0.037	0.035	0.032	0.030	0.037	0.035	0.033	0.029	0.026
Single Rafter Wood Joists (9.25" depth)														
R-25	(25.0)	0.037	0.032	0.030	0.029	0.032	0.031	0.029	0.027	0.032	0.031	0.029	0.026	0.024
R-30C	(30.0)	0.031	0.028	0.027	0.025	0.028	0.027	0.025	0.024	0.028	0.027	0.026	0.023	0.022
Single Rafter Wood Joists (11.25" depth)														
R-30	(30.0)	0.031	0.028	0.026	0.025	0.028	0.027	0.025	0.024	0.028	0.027	0.025	0.023	0.021
Single Rafter Wood Joists (13.25" depth)														
R-38	(38.0)	0.025	0.023	0.022	0.021	0.023	0.022	0.021	0.020	0.023	0.022	0.021	0.020	0.019
Metal Truss at 4 feet on center, non-metallic roof deck														
None	(0.0)	0.490	0.170	0.130	0.100	0.170	0.140	0.100	0.083	0.180	0.130	0.110	0.078	0.061
R-11	(10.1)	0.082	0.063	0.056	0.051	0.063	0.058	0.051	0.045	0.063	0.057	0.052	0.044	0.038
R-19	(16.2)	0.055	0.045	0.042	0.039	0.046	0.043	0.039	0.035	0.046	0.042	0.039	0.034	0.031
R-30	(23.7)	0.039	0.034	0.032	0.030	0.034	0.033	0.030	0.028	0.034	0.032	0.030	0.027	0.025
R-38	(27.7)	0.034	0.030	0.028	0.027	0.030	0.029	0.027	0.025	0.030	0.028	0.027	0.025	0.023

Note: U-values are calculated using methods from ASHRAE Handbook 1989 Fundamentals, Chapter 22. These are summer U-values, for downward heat flow.

Table 3-N Typical U-Values for Opaque Walls (Btu/h-ft^2-°F)

(From ASHRAE Standard 90.1-1989 User's Manual)

Nominal Insul. R-value	Effective Insul. R-value	U-value	Expanded Polystyrene 1.0" R3.8	1.5" R5.7	2.0" R7.6	Extruded Polystyrene 0.75 R3.7	1.0" R5.0	1.5" R7.5	2.0" R10.0	Polyisocyanurate 0.5" R3.6	0.75 R5.4	1.0" R7.2	1.5" R10.8	2.0" R14.4
						2 x 4 Metal Framing at 16 inches on center (3.5 inch cavity depth)								
None	(0.0)	0.403	0.159	0.122	0.099	0.162	0.134	0.100	0.080	0.164	0.127	0.103	0.075	0.059
R-11	(5.5)	0.133	0.088	0.076	0.066	0.089	0.080	00.067	0.057	0.090	0.077	0.068	0.055	0.046
R-13	(6.0)	0.125	0.085	0.073	0.064	0.085	0.077	0.064	0.055	0.086	0.074	0.066	0.053	0.045
R-15	(6.4)	0.119	0.082	0.071	0.062	0.082	0.074	0.063	0.054	0.083	0.072	0.064	0.052	0.044
						2 x 4 Metal Framing at 24 inches on center (3.5 inch cavity depth)								
R-11	(6.6)	0.116	0.080	0.070	0.062	0.081	0.073	0.062	0.054	0.082	0.071	0.063	0.051	0.043
R-13	(7.2)	0.108	0.077	0.067	0.059	0.077	0.070	0.060	0.052	0.078	0.068	0.061	0.050	0.042
R-15	(7.8)	0.102	0.073	0.064	0.057	0.074	0.067	0.058	0.050	0.074	0.066	0.059	0.048	0.041
						2 x 6 Metal Framing at 16 inches on center (5.5 inch cavity depth)								
R-19	(7.1)	0.110	0.077	0.067	0.060	0.078	0.071	0.060	0.052	0.079	0.069	0.061	0.050	0.042
R-21	(7.4)	0.106	0.076	0.066	0.059	0.076	0.069	0.059	0.051	0.077	0.067	0.060	0.049	0.042
						2 x 6 Metal Framing at 24 inches on center (5.5 inch cavity depth)								
R-19	(8.6)	0.094	0.069	0.061	0.055	0.070	0.064	0.055	0.048	0.070	0.062	0.056	0.047	0.040
R-21	(9.0)	0.091	0.067	0.060	0.054	0.068	0.062	0.054	0.048	0.068	0.061	0.055	0.046	0.039
						2 x 4 Wood Framing at 16 inches on center (3.5 inch cavity depth)								
None	(0.0)	0.263	0.132	0.105	0.088	0.133	0.114	0.088	0.072	0.135	0.109	0.091	0.068	0055
R-11	(11.0)	0.088	0.066	0.059	0.053	0.066	0.061	0.053	0.047	0.067	0.060	0.054	0.045	0.039
R-13	(12.7)	0.079	0.061	0.054	0.049	0.061	0.057	0.050	0.044	0.061	0.055	0.050	0.043	0.037
R-15	(15.0)	0.070	0.055	0.050	0.046	0.055	0.052	0.046	0.041	0.056	0.051	0.046	0.040	0.035
						2 x 4 Wood Framing at 24 inches on center (3.5 inch cavity depth)								
R-11	(11.0)	0.086	0.065	0.058	0.052	0.065	0.060	0.052	0.046	0.066	0.059	0.053	0.045	0.039
R-13	(12.7)	0.077	0.060	0.054	0.049	0.060	0.056	0.049	0.044	0.060	0.055	0.050	0.042	0.037
R-15	(15.0)	0.068	0.054	0.049	0.045	0.054	0.051	0.045	0.040	0.055	0.050	0.046	0.039	0.034
						2 x 6 Wood Framing at 16 inches on center (5.5 inch cavity depth)								
R-19	(18.0)	0.058	0.047	0.043	0.040	0.048	0.045	0.040	0.037	0.048	0.044	0.041	0.036	0.032
R-21	(21.0)	0.051	0.043	0.040	0037	0.043	0.041	0.037	0.034	0.043	0.040	0.037	0.033	0.029
						2 x 6 Wood Framing at 24 inches on center (5.5 inch cavity depth)								
R-19	(18.0)	0.057	0.047	0.043	0.040	0.047	0.044	0.040	0.036	0.047	0.043	0.040	0.035	0.031
R-21	(21.0)	0.050	0.042	0.039	0.036	0.042	0.040	0.036	0.033	0.042	0.039	0.037	0.033	0.029

Table 3-O Typical U-Values For Wood and Steel Swinging Doors Btu/(h-ft^2-°F)

(From ASHRAE Standard 90.1-1989 User's Manual)

Nominal Thickness (Inches)	Description	No. Storm Door	Wood Storm Door[c]	Metal Storm Door[c]
Wood Doors[a,b]				
1-3/8	Panel door with 7/16-in panels[e]	0.57	0.33	0.37
1-3/8	Hollow core flush door	0.47	0.30	0.32
1-3/8	Solid core flush door	0.39	0.26	0.28
1-3/4	Panel door with 7/16-in panels[e]	0.54	0.32	0.36
1-3/4	Hollow core flush door	0.46	0.29	0.32
1-3/4	Panel door with 1-1/8-in panels[e]	0.39	0.26	0.28
1-3/4	Solid core flush door	0.33	0.25	0.28
2-1/4	Solid core flush door	0.27	0.20	0.21
Steel Doors[b]				
1-3/4	Fiberglass or mineral wool core with steel stiffeners, no thermal break[f]	0.60	n.a.	n.a.
1-3/4	Paper honeycomb core without thermal break[f]	0.56	n.a.	n.a.
1-3/4	Solid urethane foam core without thermal break[f]	0.40	n.a.	n.a.
1-3/4	Solid fire rated mineral fiberboard core without thermal break[f]	0.38	n.a.	n.a.
1-3/4	Polystyrene core without thermal break (18 gage commercial steel)[f]	0.35	n.a.	n.a.
1-3/4	Polyurethane core without thermal break (18 gage commercial steel)[f]	0.29	n.a.	n.a.
1-3/4	Polyurethane core without thermal break (24 gage commercial steel)[f]	0.29	n.a.	n.a.
1-3/4	Polyurethane core with thermal break and wood perimeter (24 gage commercial steel)[f]	0.20	n.a.	n.a.
1-3/4	Solid urethane foam core with thermal break[a]	0.19	0.16	0.17

Note: All U-Values for exterior doors in this table are for doors with no glazing, except for the storm doors which are in addition to the main exterior door. Any glazing area in exterior doors should be included with the appropriate glass type and analyzed. Interpolation and moderate extrapolation are permitted for door thicknesses other than those specified.

a Values are based on a nominal 32 by 80 in. door size with no glazing.

b Outside air conditions: 15 mph wind speed, O°F air temperature; inside air conditions: natural convection, 70°F air temperature.

c Values for wood storm door are for approximately 50% glass area.

d Values for metal storm door are for any percent glass area.

e 55% panel area.

f ASTM C 236 hotbox data on a nominal 3 by 7 ft door size with no glazing.

Source: ASHRAE Handbook 1989 Fundamentals, p. 22.12, Table 6.

Table 3-P Default U-Values For Sliding and Roll-Up Doors Btu/(h-ft^2-°F)

(From ASHRAE Standard 90.1-1989 User's Manual)

Door Description	Overall U-Factor
Uninsulated, single-layer	1.15
Nominal 2" thick with 1-3/4" polyurethane foam core and vinyl thermal breaks and section joint seals	0.14
Nominal 3" thick with 2-7/8" expanded polystyrene core and continuous vinyl extrusion to form a thermal break and weather-tight seal along section joint	0.12
Other doors	Use value from most similar swinging door above

Table 3-Q Effective R-Value of Fiberglass Batts That Are Compressed In Various Depth Cavities ($h\text{-}ft^2\text{-}°F/Btu$)

(From ASHRAE Standard 90.1-1989 User's Manual)

Nominal Lumber Size	Actual Depth of Cavity	Insulation R-values at Standard Thickness													
		38C	38	30C	30	25	22	21	19	15	13	11	8	5	3
2"x12"	11-1/4"	38	37												
2"x10"	9-1/4"		32	30											
2"x 8"	7-1/4"		27		26	24									
2"x 6"	5-1/2"				21		20	21	18						
2"x 4"	3-1/2"						14		13	15	13	11			
2"x 3"	2-1/2"										10				
2"x 2"	1-1/2"										6.5	6.0	5.7		
2"x 1"	1/2"													3.2	3.0

The standard insulation thicknesses are as follows: 10-1/4" for R-38C, 12" for R-38, 8-1/4" for R-30C, 9-1/2" for R-30, 8" for R-25, 6-3/4" for R-22, 5-1/2" for R-21, 6-1/4" for R-19, 3-1/2" for R-15, 3-1/2" for R-13, 3-1/2" for R-11, 2-1/2" for R-8, 1-1/2" for R-5 and 3/4" for R-3.

Table 3-R Engineered Metal Buildings (Based on 5 Foot Purlins Spacing)

(From ASHRAE Standard 90.1-1989 User's Manual)

Nominal R-value	Standard Installation - Insulation Laid Over Purlins and Compressed (U-values)	Insulation Laid out Parallel to and between Purlins and not Compressed, Plus R-Thermal Block Separating Purlins from Roof Deck (U-values)
R-6	0.20	0.12
R-10	0.14	0.09
R-13	0.12	0.08
R-19	0.09	0.07

Visible Light Transmission (VLT)

Visible light transmission (VLT) is the fraction of solar radiation in the visible spectrum that passes through the fenestration. VLT is used with the system performance requirements.

The VLT is published by glazing product manufacturers with their technical literature. It is based on light approaching the glass at a normal incidence, similar to the shading coefficient. Typical values are included in this manual in Table 3-K.

There is a strong relationship between the visible light transmission and the shading coefficient. The lower the shading coefficient, generally the lower the visible light transmission. Some glazing products, however, have a VLT higher than other products with the same shading coefficient. For instance, bronze, gray and green tinted glass all have about the same shading coefficient for a given glass thickness, but green glass has a significantly higher visible light transmission. Likewise, some coatings applied to the surface of glazing result in a higher relative VLT than other glazing products. For these reasons, manufacturer's literature should be carefully consulted in the selection of glazing products.

Window Wall Ratio (WWR)

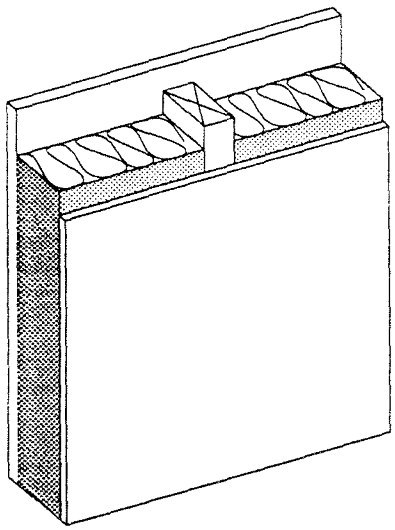
Window wall ratio is the percentage of the gross exterior wall area (including fenestration) which is covered by windows. It is equal to the fenestration area divided by the exterior wall area (see *surface definitions*).

For the prescriptive window requirements, the maximum RSHG is based on WWR and it varies for the north side and the combined east, south and west sides. Therefore, two values for WWR are needed, one for the north and one for the other three sides.

Example 3-J Thermal Transmittance – Series and Parallel Path

Q

What is the thermal transmittance of the wood framed wall shown in the following drawing?



Outside Air Film

7/8 inch Stucco

2 x 4 Wood Studs with R-13 in the Cavity

5/8 inch Gypsum Board

Inside Air Film

A

The series and parallel path method may be used for this type of construction. The U-value is calculated separately for the cavity and framing portions of the wall based on the thermal resistance of each element of the wall. These calculations are made in the following table

	Cavity	Framing
Outside air film	0.17	0.17
7/8 inch stucco	0.18	0.18
Building paper	0.06	0.06
Cavity insulation	13.00	
Framing		3.47
5/8 inch gypsum board	0.45	0.45
Inside air film	0.68	0.68
Sum of thermal resistance	14.54	5.01

The estimated framing percent is 11% of the wall area and the U-value may be calculated as shown below.

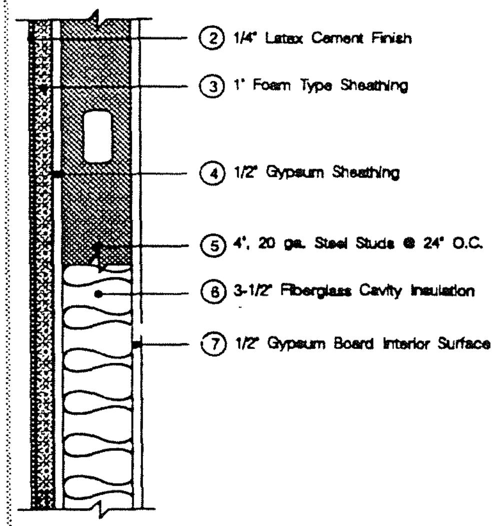
$$U = \frac{0.11}{5.01} + \frac{1 - 0.11}{14.54} = 0.083$$

The maximum allowed U-value for wood framed walls is 0.10, so this wall complies.

Example 3-K Thermal Transmittance – Effective R-Value

Q

What is the thermal transmittance of the metal framed wall shown in the following drawing?



Component	R-value
(1) Exterior air film	0.17
(2) Latex Cement Finish	0.21
(3) Foam Sheathing	4.00
(4) Gypsum Sheathing	0.45
(5) 2X4 Steel Studs 24" O.C.	N.A.
(6) Fiberglass Insulation	11.00
(7) Gypsum Board Interior	0.45
(8) Interior vertical air film	0.68

A

For this metal-framed wall the effective R-value of the combined cavity insulation and metal framing may be used in a simple series calculation. This method is available for wall sections with non-metal skin attached to metal stud framing. The effective R-value of R-11 insulation in a 2x4 metal stud wall spaced at 24 inches on center is 6.6 (see Table 3-J). The thermal transmittance of this assembly is then:

$$\sum_i R_i = 0.17 + 0.21 + 4.00 + 0.45 + 6.60 + 0.45 + 0.68 = 12.56$$

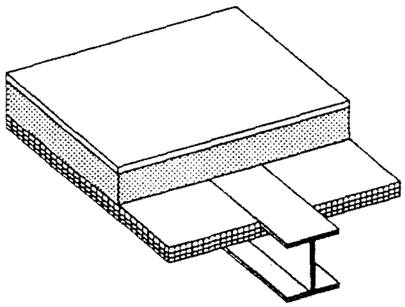
$$U = \frac{1}{R} = \frac{1}{12.56} = 0.080$$

The maximum allowed U-value for metal-framed walls is 0.15, so this wall construction complies.

Example 3-L Thermal Transmittance – Zone Method

Q

What is the thermal transmittance of the roof assembly shown in the following drawing?



Single Ply Roof Membrane

4-inch Concrete Slab

1/2 inch Extruded Polystyrene

WF8x8 Steel Structure at 4 ft o.c.

A

The zone method may be used for this type of construction. The zone method is presented in Chapter 22 of the ASHRAE Handbook of Fundamentals (1989). It is recommended for constructions with widely spaced metal structural members that are attached to non-metal sheathing. The zone method divides the construction into two parallel path constructions (zones); a zone affected by the steel members, and a zone not affected by the steel members. The overall width of the two zones is 48 inches, the spacing of the steel members. The width of the zone containing the steel structure (Zone A) is given by the equation:

$$W = m + 2 \times d = 8" + 2 \times 4" = 16"$$

where

m = the width of the I-beam flange

d = the distance from the top flange to the roof surface

This 16" wide zone is centered on the steel members. The calculation of parallel path U-values is given below.

	Zone A (32" wide, without steel member)		Zone B (16" wide - with steel member)	
Item	R-Value (Btu/h-°F-ft^2)	U-Value=1/R (h-°F-ft^2/Btu)	R-Value (Btu/h-°F-ft^2)	U-Value=1/R (h-°F-ft^2/Btu)
1) Outside air layer	0.17	6.0	0.17	6.0
2) Roofing	0.33	3.0	0.33	3.0
3) 4" Slab (Lightweight)	2.41	1.66/4=0.42	2.41	0.42
4a) 1/2" Polystyrene	2.50	0.20/0.5=0.40	2.50	0.40
4b) 1/4" thick steel webbing	N.A.	N.A.	0.00	314.4/0.5=628.80
4) Polystyrene and web	2.50	0.40	0.00	(0.4X8+628.8X8)/16=314.6
5) Inside air layer	0.61	1.63	0.61	1.63
Total R-value for each zone (Σ R)	6.02		3.52	
Total U-value for each zone (1/Σ R)	0.17		0.28	

$$U_o = \frac{U_{ZoneA} \times Width_{ZoneA} + U_{ZoneB} \times Width_{ZoneB}}{Width_{Total}} = \frac{0.17 \times 32" + 0.28 \times 16"}{48"} = 0.21 \frac{h - ft^2 - °F}{Btu}$$

Roof compliance depends on surface color as well as U-value (see roof heat gain factor) and Table 3-C shows that 0.21 will not comply, even with a bright white roof surface (maximum is 0.17). More insulation or a radiant barrier is required.

4. Ventilation and Air Conditioning

General Information

This chapter covers Articles 9, 10 and 12 of the Hawaii Model Energy Code which deal with the design, construction and control of mechanical ventilation and air conditioning systems. Article 9 addresses system design. Article 10 specifies minimum equipment efficiency levels. Article 12 addresses energy management controls. This chapter is intended for the mechanical engineer or contractor with responsibility for the design and/or construction of ventilation and air conditioning systems, but some of the information on energy management (Article 12) applies to all energy uses within the building.

Introduction

HVAC systems and equipment are one of the most significant users of energy in air conditioned buildings - representing 35% to 45% of energy use in typical offices in Hawaii. In such buildings, HVAC energy consumption is on par with lighting. However, the designer has significant latitude in the energy costs and consumption of HVAC systems: a poorly designed system can easily have twice the yearly energy costs of an energy conserving design.

Analyzing the energy use and cost of an HVAC system is complicated by system interactions. An efficient system is not merely characterized as one that uses efficient equipment. System level efficiency must account for installation, control, maintenance, system losses and component interactions (such as reheat or heat recovery). An efficient system will minimize energy use by minimizing system losses, maximizing equipment efficiencies, utilizing free heating/cooling and recovering heat where possible.

In addition, good operating and maintenance techniques are essential to achieve the energy efficiency contemplated in the design.

Article 9 of the Code addresses the following fundamental factors to improve HVAC system efficiency:

- Reducing system losses from ductwork and piping
- Reducing system operation through the use of automatic time controls and zone isolation
- Reducing system operation through requirements for zonal controls
- Reducing system inefficiencies by limiting equipment oversizing
- Reducing distribution losses, limiting HVAC fan energy demand, and requiring efficient balancing practices

Article 10 requires minimum equipment efficiency and Article 12 has requirements for measuring and monitoring energy used by HVAC systems.

Although compliance with Articles 9, 10 and 12 of the Code assure a minimum design level of HVAC system and equipment performance, the designer is encouraged to view the requirements as a starting point and investigate designs that exceed these minimums. For example, application of heat recovery or high efficiency equipment can both create a system that is more efficient than the Code requires and exhibit an excellent return on investment.

Scope

The ventilation and air conditioning requirements apply to both new buildings and to new systems installed in existing buildings. For existing buildings, the code applies only to equipment or systems that are being installed or replaced. For instance, if only the air distribution system is being replaced, only the requirements for the air distribution system are applicable. It is not necessary to upgrade the fan or refrigeration equipment. Maintenance and repair of existing systems is exempt from the Code.

Compliance Methods

Most of Article 9 and all of the requirements of Articles 10 and 12 are basic requirements that must be met for all compliance paths, including the energy cost budget method. There is no system performance method for HVAC systems. Unless the energy cost budget method is used, the prescriptive requirements of Article 9.4 must be satisfied.

Application by System Type

Many of the requirements of Article 9 apply to larger, multiple zone systems. The breadth of the article may seem overwhelming to designers of simpler, single zone systems. Table 4-A below may help designers identify measures that are applicable to their system design.

Example 4-A HVAC Equipment Replacement and Repair

Q

An office building has a broken-down 1-year old packaged air conditioner. The owner must decide to buy a new unit or replace the compressor in the existing unit. How do the HVAC requirements apply in either case?

A

If the whole unit is replaced, then the new equipment must meet the relevant efficiency requirements of Article 10. If the compressor or some other part of the existing unit is replaced, then the requirements do not apply because repairs are exempt.

Example 4-B Retail Renovation

Q

A bookstore in a small shopping mall is to be subdivided to provide space for a beauty parlor and a nail salon. The chilled water pipes must be rerouted to supply two new smaller fan coils. The existing central chiller is adequate to meet the cooling load. How do the HVAC requirements apply?

A

The code applies only to portions of the system that are replaced. Therefore, the new pipes must be insulated, and the fan coils must be properly sized. The code does not require that the remainder of the existing system be upgraded.

Table 4-A Applicable Article 9 Requirements for Different HVAC Systems

(adapted from ASHRAE Standard 90.1 - 1989 User's Manual)

Section	Applicability Notes
Basic Requirements	
Load calculations 9.3(a)	All systems
Separate systems 9.3(b)	No requirements for single zone systems
Unit temperature control 9.3(c)(1)	All systems
Zone temperature controls 9.3(c)(2)	All systems, special requirements for perimeter heating systems
Shutdown controls 9.3(d)(1)	All systems
Isolation controls 9.3(d)(2)	All systems in projects over 25,000 ft^2 in size
Hotel door interlock controls 9.3(d)(3)	Hotel and motel guest rooms only
Humidity controls 9.3(e)	All humidification or dehumidification systems
Ventilation air 9.3(f)	All systems
Pipe insulation 9.3(g)(2)	All hydronic and split systems. No requirements for unitary equipment v condensers.
Duct insulation 9.3(g)(3)	All systems
Duct construction 9.3(g)(4)	All systems
Energy recovery 9.3(h)	Systems greater than 10 tons with coincident hot water load
Completion 9.3(i)	All systems
Cooling unenclosed spaces 9.3(j)	Systems providing cooled air to unenclosed spaces
Prescriptive Requirements	
Equipment sizing 9.4(a)	All systems
Zone controls for reheat and recool 9.4(b)	No requirements for unitary single-zone systems. Prohibits constant volume reheat. Restricts VAV and multizone systems
Fan sizing criteria 9.4(c)	No requirements for unitary equipment where fan energy is part of the unit rating
Pumping system design 9.4(d)	All hydronic systems
System temperature reset controls 9.4(e)	No requirements for unitary single zone systems

System Basic Requirements

Load Calculations

The designer must make heating and cooling load calculations before selecting or sizing HVAC equipment. The purpose of this requirement is to ensure that equipment is neither oversized nor undersized for the intended application. Oversized equipment not only increases owner costs, but usually operates less efficiently than properly sized equipment. It can also result in reduced comfort control due to, for example, lack of humidity control in cooling systems and fluctuating temperatures from short-cycling. Undersizing will obviously result in poor temperature control in extreme weather.

While load calculations are required, there is no basic requirement that actual equipment sizes correspond to the calculated loads. This correspondence is required only for the prescriptive method (Section 9.4). For buildings complying by the energy cost budget method (Article 13), calculations are still required, but equipment sizing is at the discretion of the designer. Oversizing using the energy cost budget method is effectively limited because the energy budget is based on a system that is not oversized. While the size of equipment in the proposed design is not strictly limited, the inefficiencies resulting from oversized equipment will be accounted for by the simulation program, making compliance more difficult.

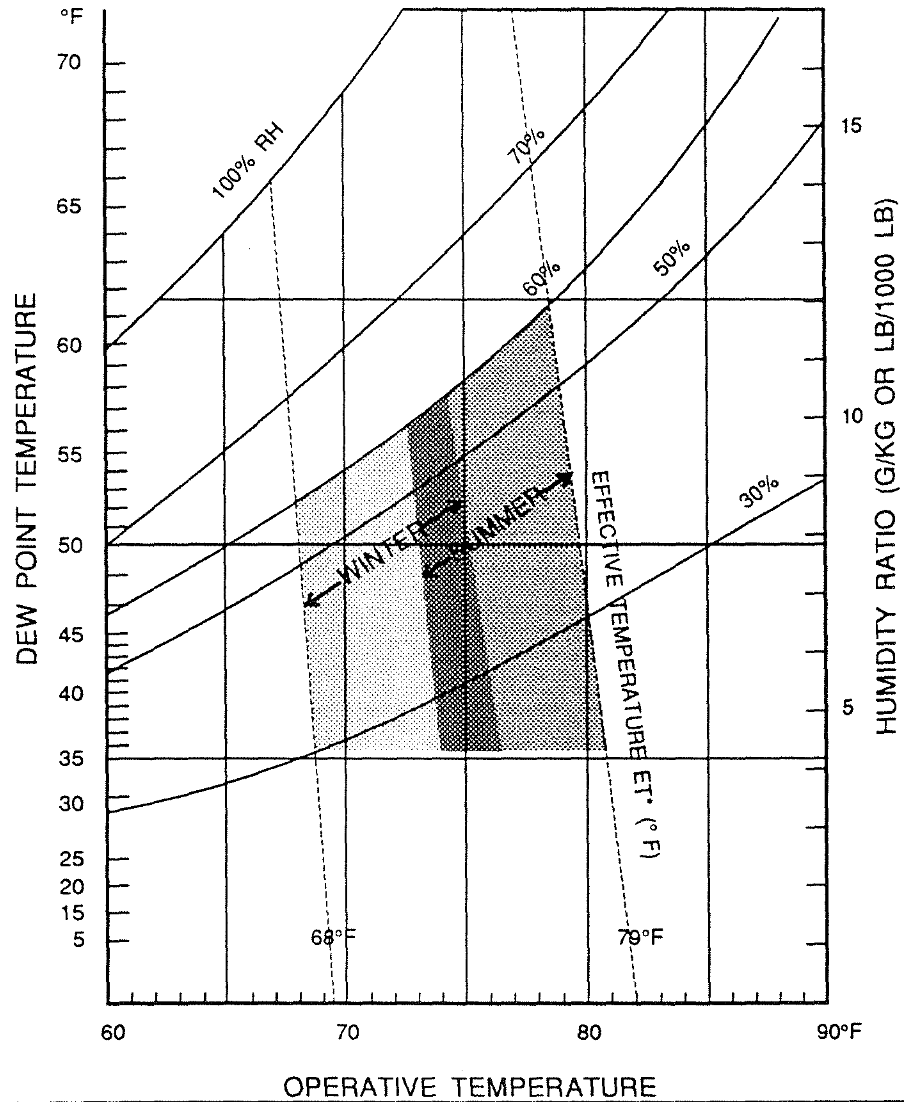
Accurate calculation of expected cooling loads begins with a reliable calculation methodology. The Hawaii Energy Code requires in Article 9.3(a)(1) that calculation procedures be in accordance with the ASHRAE Fundamentals Handbook, (1993) Volume "*or a similar computation procedure*." The latter phrase is included to allow the use of other time-proven methodologies that may not precisely follow ASHRAE procedures, such as those developed by some major equipment manufacturers and other professional groups.

There is no universal agreement among engineers on a single load calculation procedure at this time, and the available procedures produce results that vary considerably. This is because the dynamic thermodynamic performance of buildings and HVAC systems is so complicated that all calculation methods and computer software must have simplifying assumptions embedded within them to make them practical to use. Depending on application, these simplifications can result in inaccuracies and errors. The designer should be aware of the limitations of the calculation tool used and apply "reality checks" to the results, based on past "real life" experience, to avoid sizing errors.

Once a reliable calculation procedure is selected, accurate load calculations then depend on the use of accurate design parameters. The Hawaii Model Energy Code restricts many parameters, but leaves room for flexibility and judgment on the part of the designer.

The following design parameters are restricted:

Figure 4-A The ASHRAE Comfort Envelope
(from ASHRAE Standard 55 - 1992)



Indoor Design Conditions

Indoor temperature and humidity must be in accordance with the comfort criteria established in ASHRAE Standard 55-1992, or Chapter 8 of the ASHRAE Fundamentals Handbook, (1993) Volume.

The perception of thermal comfort is a function of many variables including air temperature, radiant temperature, air movement, gender, clothing, activity level, age, and adaptation to local climate. Therefore, there is no single design temperature or humidity recommended by ASHRAE to achieve acceptable comfort.

Figure 4-A depicts the so-called "ASHRAE comfort envelope" from Standard 55 (also described in Chapter 8 of the ASHRAE Fundamentals Handbook, (1989) Volume). The shaded areas – entitled "winter" and "summer" – show the range of conditions that 80% of sedentary people dressed in typical

clothing in still air will find acceptable. The abscissa, "operative temperature," is a weighted average coefficient made from the space dry-bulb temperature and mean radiant temperature. The mean radiant temperature is a weighted average temperature of room surfaces (walls, ceiling, floor): in most buildings with reasonably designed envelopes (those with insulated walls and glazing), it will be close to the space dry bulb temperature; in spaces dominated by single-pane window walls, the mean radiant temperature will be closer to the outside air dry-bulb temperature. The diagonal lines – entitled "effective temperature ET*" – are comfort weighted dry-bulb space temperature which accounts for the effects of humidity (referenced to 50% relative humidity).

The summer comfort envelope extends up to operative temperatures as high as 78°F to 80°F depending on the humidity. However, practical experience and recent research suggests that the comfort range in commercial applications may actually be much lower, with its outer border near the outer border of the winter comfort band (around 73°F to 76°F depending on relative humidity). Designers should be aware of this if selecting higher design cooling temperatures for comfort HVAC applications since, regardless of energy consequences, the ultimate purpose of the HVAC system is to maintain comfort.

The comfort envelope also suggests that humidity should not rise above 60%. Humidity may rise above 60% in Hawaii despite the dehumidification that occurs inherently in the cooling process. While dehumidification may be desirable and may be provided at the designer's discretion, The Hawaii Model Energy Code does not require these systems nor does it prescribe that minimum or maximum design humidity levels be used in load calculations.

The comfort envelope applies only to sedentary people wearing typical clothing. It may be necessary to adjust conditions to expected clothing levels in the space (e.g. doctors' examination rooms), occupant age (e.g. retirement homes), and activity level (e.g. gymnasia). Refer to ASHRAE Standard 55-1992 for more information.

Outside Design Conditions

If not in conflict with State Health Department regulations, outdoor design weather data must be taken from ASHRAE SPCDX Weather Data for Region X (Arizona, California, Hawaii and Nevada). Design heating temperatures must be no lower than the value listed in the 0.2% column (0.2% of the hours in the typical year are colder), and cooling design temperatures be no higher than the 0.5% values (only 0.5% of the hours each year are warmer).

Ventilation

Base the loads on the minimum design ventilation rates defined in section 9.3(f). See further discussion under *Ventilation* below.

Envelope

Envelope performance parameters, such as thermal transmittance (U-values), shading coefficients of fenestration, wall and glazing areas, etc. must be consistent with the values used to show compliance with Article 8. For instance, if credit is taken for a low transmission glass in Article 8, the same glass must also be assumed for HVAC load calculations.

Take care to account accurately for the potentially significant effect of wall and window framing systems on thermal conductance to avoid seriously underestimating loads. Thermal bridging is particularly significant for metal framing which can reduce the insulating effect of wall insulation or double glazing by 50% or more. See Chapter 3 of this manual for further information.

Table 4-B Outside Design Conditions for Hawaii, °F

Location	Summer, 0.5% values		Winter, 0.2% values
	DB/WB [a]	WB	DB
Kauai			
Eleele (Hanapepe)	85/74	77	58
Hanalei	87/75	76	60
Kokee Air Force Station	80/66	69	47
Lihue	84/74	76	58
Oahu			
Barbers Point	87/75	77	59
Honolulu Airport	87/75	76	61
Kaena Point	83/72	74	54
Kaneohe Bay MCAS	85/74	76	64
Molokai Airport	87/74	76	60
Lanai City	81/70	73	56
Maui			
Haleakala Summit	64/46	62	29
Hana	85/74	61	29
Kaanapali	87/75	79	60
Kahului Airport	90/76	77	57
Hawaii			
Hawaii Volcanos NP	76/64	68	47
Hilo	85/74	75	60
Kona (Kailua)	86/74	76	63
Waimea	80/68	71	46

[a] Drybulb and mean coincident wetbulb temperatures.
Note: data for more locations is available in *Climatic Data for Region X Arizona, California, Hawaii, Nevada*, Golden Gate and Southern California Chapters, ASHRAE, May 1982.

Lighting

The designer must base cooling loads on lighting power levels consistent with those used to show compliance with Article 6 of the Code.

Other loads

Internal cooling loads due to people, equipment such as computers and copiers, etc. are often difficult to predetermine because they vary so much from one building to another. The Hawaii Model Energy Code leaves the designer a great deal of flexibility in determining design parameters for these miscellaneous loads, requiring only that they be compiled from one or more of the following sources:

- Actual information based on the intended use of the building. For instance, the exact occupancy of a theater can be determined by the number of seats.
- Published data from manufacturers' technical publications. This is most useful for large data processing equipment for which data is readily available. But take care to use the data correctly; in most cases equipment manufacturers list peak operating power at which the equipment will usually only operate for a relatively short period of time. For instance, a copy machine will use much less power when idling than when copying. A laser printer will operate at peak power only a few seconds each hour when its toner heater operates. The designer should apply an appropriate load diversity factor to such equipment when it is known to operate intermittently. Other manufacturers' equipment ratings are

similiarly misleading, particularly those for popular personal computers and peripherals. This can lead to significant cooling system oversizing. Table 4-C lists actual power requirements for several common PC products. These data, rather than manufacturers' data, should be used for cooling system sizing.

Technical publications such as the ASHRAE Applications Handbook (1991) and a paper by Alereza, et. al., "Estimates of Recommended Heat Gains Due to Commercial Appliances and Equipment" (particularly applicable to kitchens and hospitals and substantially reprinted in the ASHRAE Fundamentals Handbook, (1993), Chapter 26, Tables 6 through 8) are particularly useful.

- Default values used in determining design energy budgets in Article 13, Tables 13-1 and 13-2 provide load densities for people and miscellaneous equipment. These load densities should be considered "rules-of-thumb" and should be used only if actual data are not available.

As with lighting, internal loads from people and equipment heat gains may be ignored for heating load calculations.

Safety Factor

Once total heating and cooling loads have been determined from the data and procedures outlined above, they may be increased by as much as 10% to allow for future added loads or unexpected loads that may arise as space usage changes.

Pick-up loads

ASHRAE load calculation methods take into account some of the effects of thermal mass as it affects cooling loads. For instance, solar heat gain factors vary as a function of space mass, accounting for the delay from the time solar radiation is absorbed by the room floor and furnishings until it convects to the room air and becomes an air conditioning load some time later. Similar factors are applied to internal gains such as lights and people. But these methods generally assume that the space is maintained at relatively constant temperatures, and thus the loads they predict often are referred to as steady state loads.

When HVAC systems are operated intermittently, the system must be capable of warming up or cooling down spaces whose temperatures have been left to float out of comfortable ranges. These are called pick-up loads. The Code allows two methods for determining these loads:

- They may be calculated from basic principles, based on the heat capacity of the space, the setback or setup temperatures and the amount of time allowed to bring the space to operating temperatures. While this method would seem to be capable of producing the most accurate answers, in practice, it is seldom used because the heat transfer modes are so complicated. For instance, the internal walls and floors of a building, and much of its furnishings, seldom reach a steady state condition during setback. Although the air in the space may have risen or dropped in temperature significantly during HVAC system shut-down, most of the building mass has not, lagging behind due to its heat capacity and the limited heat transfer avenues to the space air. Thus to assume in pick-up load calculations that the entire mass of a building was cooled or heated to the setback/setup temperature would result in grossly oversized HVAC equipment. The non-steady-state heat transfer that occurs as spaces warm-up or cool-down complicates calculations even further.
- Because of the complications of applying basic principles, by far the most common method to calculate pick-up loads is to apply warm-up or

Table 4-C Rated Vs. Measured Loads (Watts) for Selected Equipment

(from ASHRAE Standard 90.1- 1989 User's Manual)

Equipment Type And Model	Cases	Rated Power	Measured Power Average	Measured Power Peak
IBM PC	3	240	93	100
IBM XT	4	440	115	123
IBM AT	2	500	160	170
IBM PS-2/30	1	212	76	78
IBM PS-2/50	1	322	109	109
IBM PS-2/60-80	3	566	176	190
Macintosh	5	100	40	41
Macintosh II	3	481	109	133
Compaq Portable I	3	224	98	122
Compaq Port.III	1	288	85	90
Atari 1040ST	1	118	46	49
NeXT	1	n.a.	126	129
Laptop PCs	6	21	10	31
Printers	9	n.a.	18	94
Laser Printers	2	n.a.	135	274
Copiers	3	n.a.	445	763

Measured power includes computer, monitor and screen. Except as noted, measured power is an average of several short-term measurements. Value reported is the average of all the cases measured.

For printers, the "average" column refers to the power draw when in standby mode (not printing); "peak" refers to typical usage when printing. Value reported is the maximum of all the measured cases.

Copiers were monitored during actual usage conditions for one to two weeks. The "peak" value refers to the maximum hourly average demand. "average refers to 24-hour average from Monday through Friday.

cool-down factors to the steady-state loads calculated by conventional methods. The Code allows steady-state heating loads to be increased by as much as 30% and steady-state cooling loads to be increased by as much as 10% to allow for pick-up. The starting steady-state loads may include the 10% safety factor. The heating load warm-up factor is larger than the cool-down factor because warm-up generally occurs in the morning at the same time that peak heating loads occur. On the other hand, cool-down loads generally occur before solar loads and many internal heat gains are present, so the cool-down factor need not be as large.

Example 4-C Calculation of Typical PC Loads

Q

An HVAC system is to be designed for a speculative high rise office building. Expected tenants will include mostly accountants and lawyers. What internal loads from personal computers, printers, copy machines, etc. should be used to size the system?

A

There is no "right" answer to this question. The designer must make an educated estimate of expected loads, recognizing that overestimating loads will increase costs and possibly energy usage, while an underestimate can increase costs at a later date since increasing capacity after the building is built will be expensive.

For this exercise, consider personal computers, printers and copiers. It is reasonable to assume one computer for each person, one printer for each four persons and one copy machine for each 10 persons. Occupant density is typically about 7 persons per 1,000 ft^2 of floor area (the ASHRAE Standard 62-1989 recommendation). Using these assumptions with the data from Table 4-C estimates of equipment load range from a low of 0.62 W/ft^2 if the least power equipment is used to a high of 1.78 if the highest power equipment is used. the calculations are summarized in the following table.

		Average Equipment Power (W)		Average Power Density (W/ft^2)	
		High	Low	High	Low
Personal Computers	1 per person	176	40	1.23	.28
Printers	1 per 4 persons	135	18	.24	.03
Copiers	1 per 10 persons	445	445	.31	.31
			Total	1.78	0.62

Separate Air Distribution Systems

Often spaces housing temperature or humidity sensitive equipment or processes are located adjacent to spaces that need only comfort conditioning. To avoid the energy that would be wasted by over-conditioning the non-process spaces, the Code requires that they be served by separate air handling systems, one controlled for comfort purposes and the other controlled as required by the process. Alternatively, the two spaces may be served by a single system if it is controlled only as required for comfort, while supplementary equipment (such as humidifiers, auxiliary cooling equipment) is added to maintain the process requirements.

Separate air distribution systems are not necessary if the spaces requiring comfort conditioning use no more than 25% of the total system supply air quantity or if they do not exceed 1,000 square feet.

It is recommended (although not required) that zones with substantially differing load characteristics be served by separate air distribution systems. For instance, interior spaces which have a relatively constant requirement for cooling

Example 4-D Zoning With Process Humidity Control Requirements - Computer Center

Q

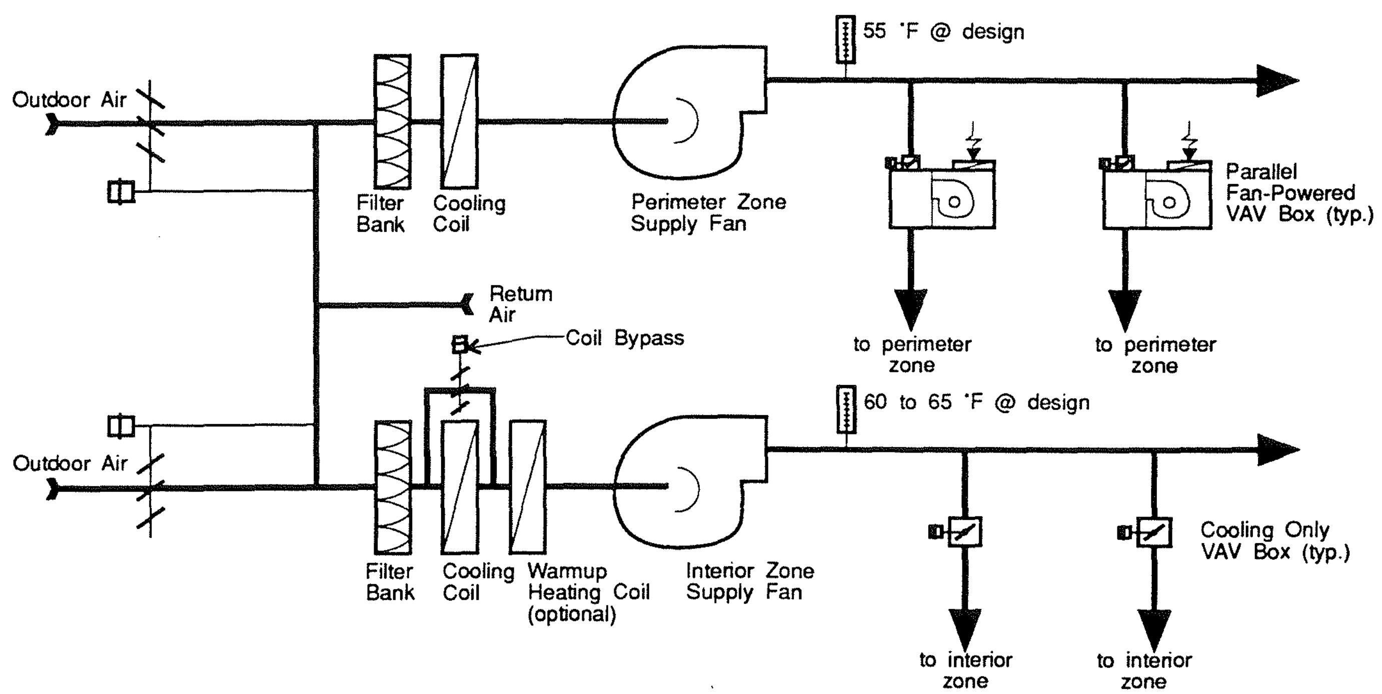
A computer center has 10,000 ft^2 of data processing area that must be maintained within tight temperature and humidity ranges. Adjacent to this area are 5,000 ft^2 of offices, tape storage, and other support spaces. For simplicity, the designers are considering serving these support spaces with the same raised floor systems serving the computer room. Would this design comply with the Code?

A

It would only comply if the total air flow required to condition the support spaces was less than 25% of the total air flow of systems serving both the computer area and support spaces. Otherwise, separate systems would have to be installed to serve the support spaces, controlled only for comfort.

Figure 4-B Recommended Separate Interior and Perimeter Fan Systems

(from ASHRAE Standard 90.1- 1989 User's Manual)



regardless of weather conditions, should be served by systems separate from those serving perimeter spaces whose loads are more dependent on solar loads. Zonal systems, such as single-zone packaged units, fan-coils, hydronic water-cooled packaged units, room air conditioners, etc. meet this requirement inherently since each zone is served by a separate system. But central, multiple zone systems such as VAV systems are often designed to serve many zones that may have widely varying load characteristics. This can lead to some inefficiencies.

Another inefficiency may arise in interior zones: in order to keep perimeter zone supply volumes reasonable at peak cooling conditions, design supply air temperatures may generally be in the range of 50°F-60°F. This may result in supply quantities that are too low for good circulation in interior spaces, particularly those designed with energy efficient lighting. To resolve this many designers install fan-powered boxes in interior spaces that mix plenum air with supply air to keep overall supply volumes up. This wastes energy by requiring that air first be overcooled and then reheated with plenum air warmed by recessed light fixtures. Also, the fan-powered box fans and motors are typically inefficient, often requiring more power than even a central fan despite the higher duct losses typical of central systems.

In general these inefficiencies result in only relatively small energy losses, so in most applications, installing separate systems for interior and perimeter zones would not be cost effective. That is why it is only recommended and not a requirement.

Zone Temperature Controls

An HVAC thermostatic control zone is defined as a space or group of spaces whose load characteristics are sufficiently similar that the desired space conditions can be maintained throughout with a single controlling device. The Code requires that the supply of cooling to *each* such zone be controlled by an *individual* temperature controller that senses the temperature within the zone.

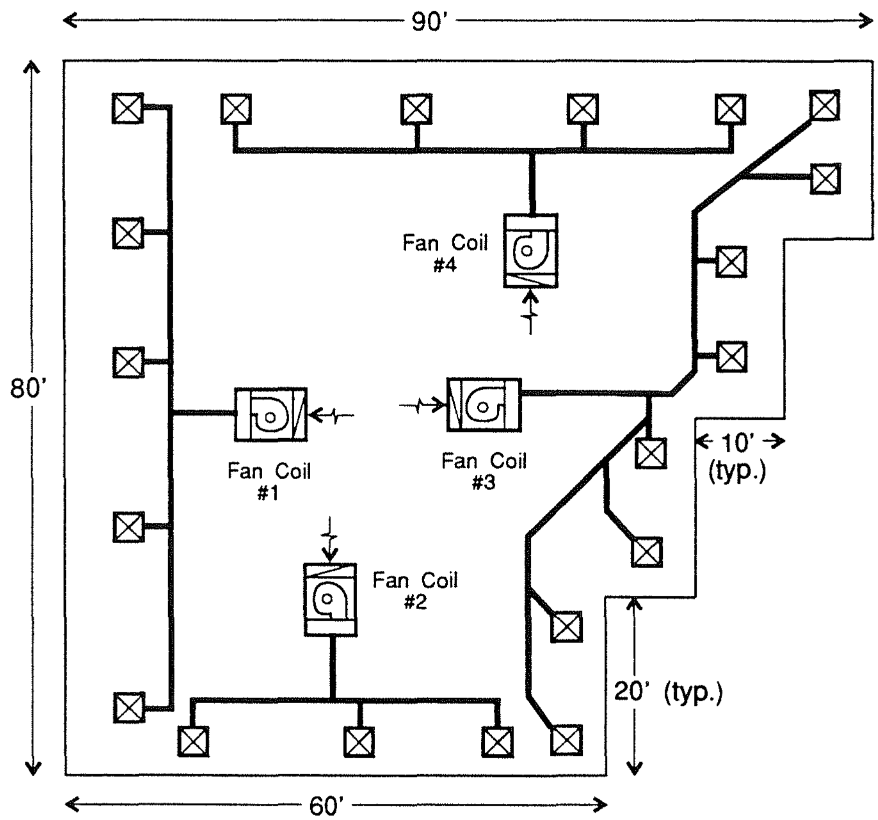
To meet this requirement, spaces must be grouped into proper control zones. For instance, spaces with exterior wall and glass exposures must not be zoned with interior spaces. Similarly, spaces with windows facing one direction should not be zoned with windows facing another orientation unless the spaces are sufficiently open to one another that air may mix well between them to maintain uniform temperatures.

Exception – Two Independent Systems

a) This exception applies to zones, typically perimeter offices, that are served by two independent HVAC systems. One of the two systems, called the perimeter system, is designed to offset only skin loads, those loads that result from energy transfer through the building envelope. Interior loads, such as those from lights and people, are controlled by a second system called the interior system. The exception is permitted only if:

- The perimeter system has at least one zone for each major exposure, defined as an exterior wall that faces 50 contiguous feet or more in one direction. For example, in Figure 4-C, a zone must be provided for each of the exposures that exceed 50 feet in length, while the shorter exposures on the serrated side of the building need not have individual zones.
- Each perimeter system zone is controlled by one or more thermostats located in the zones served. In Figure 4-C, this requirement might be met by controlling the perimeter fan-coil by one of the thermostats controlling one of the four interior system VAV zones on the exposure. Alternatively, all four thermostat signals could be monitored and the one requiring the most cooling used to

Figure 4-C Perimeter System Zoning
(from ASHRAE Standard 90.1- 1989 User's Manual)



control the fan-coil. Finally, a completely independent thermostat could be installed in one of the rooms on the exposure to control the fan-coil, set to a setpoint that was below those controlling the VAV boxes.

Exception – Dwelling Units

b) A dwelling unit, such as an apartment or condominium may be considered a single control zone for the purpose of complying with this section. Thus the Code does not require rooms of an apartment to be zoned by exposure or by function, although it is recommended that bedrooms be zoned separately from living areas to allow for different operating temperatures during the day and at night.

Setpoint Requirements

Zone thermostatic controls used to control space cooling must be capable of being set up to 85°F or higher. Thermostatic controls may be set either locally (with adjustment buttons, switches, knobs, etc.) or remotely (such as by a DDC system). Setpoints may also be changed by replacing elements for thermostats whose setpoint is a function of the sensing element. The Code does not require nor restrict the use of locking thermostat covers or other means to restrict adjustment by occupants.

Off-hour Time Controls

Most HVAC systems serve spaces that are occupied on an intermittent basis, but in a fairly predictable manner. To reduce HVAC system energy usage during off-hours, the Code requires that HVAC systems be equipped with *automatic* controls that will shut off the system or setback setpoints. Examples of acceptable automatic controls are timeclocks, programmable time switches, energy management systems, direct digital control systems, wind-up bypass timers, and occupancy sensors.

Since the term "HVAC system" applies to all equipment that provides any or all of the ventilation or cooling functions, this section requires time controls on systems ranging from simple ventilation fans to large chiller plants.

Exceptions

There are, however, three exceptions where time controls are not required:

a) systems serving spaces that are expected to be in continuous operation. Examples include hospitals, police stations and detention facilities, central computer rooms and some 24-hour retail establishments.

b) where it can be shown that setback or shutdown will not result in an overall reduction of building energy costs. There are few cases where this might occur.

c) Small equipment, those with full load demands of 2 kW (6826 Btu/h) or less, may have readily accessible manual on/off controls in lieu of automatic controls. This exception is intended to apply to small independent systems such as conference room exhaust fans or small toilet room exhaust fans. *The intent is that all energy associated with the operation of the equipment be included in the 2 kW.* For instance, a fan-coil that would use chilled or hot water, requiring operation of a remote chiller or boiler, may use in excess of 2 kW of energy when it operates, even though the fan-coil fan itself may be less than 2 kW. In this case, the fan-coil would have to be automatically controlled, although many fan-coils may be interlocked to the same timeclock (see off-hour isolation below).

Off-hour Isolation

Large central systems often serve zones that are occupied by different tenants and may be occupied at different times. When only a part of the building served by the system is occupied, energy is wasted if unoccupied spaces are also conditioned.

To minimize this waste, the Code requires that systems serving zones that can be expected to operate non-simultaneously for 750 hours or more per year be equipped with isolation devices and controls that allow each zone to be shut off or set back individually. Zones may be grouped into a single isolation area provided:

- the total conditioned floor area of the group does not exceed 25,000 ft^2
- all zones in the group are located on the same floor

Spaces that are expected to be unoccupied only when all other spaces are unoccupied need not be isolated. For example, isolation would not be required for the entry lobby of a multipurpose building since it is occupied when any of the building areas are in operation. This lobby would not benefit from isolation since it would need conditioning whenever the HVAC system is on.

In many cases, the building's eventual occupants are unknown when the HVAC system is designed, such as speculative buildings. In that case, isolation zones may be predesignated provided they do not violate either the 25,000 ft^2 or one floor rule established above. If occupant schedules are unknown, assume that isolation will be required and make appropriate provisions in the HVAC system design.

Example 4-E Time Controls – Hotel Guest Rooms

Q

Does a hotel guest room fan-coil require individual time clock controls?

A

No. Hotel guest rooms, while not actually continuously occupied, are continuously available for occupancy and thus fall under exception (a). However, systems that automatically setback or setup thermostat setpoints when rooms are not rented may be cost effective.

Example 4-F Time Controls – Fan Powered Mixing Boxes

Q

A VAV system has fan powered mixing boxes on exterior zones. Do the fans have to be automatically shut off at night?

A

In most cases, the fans in fan-powered boxes will be less than 2 kW and thus would not need *automatic* shut-off controls. However, they would still require readily accessible manual controls, which would be inconvenient and relatively expensive to install. It would be less expensive to interlock the fans with a primary air differential pressure switch, so the fans would shut off when the main fan shut–off. For pneumatically controlled systems, interlock to a control air pressure switch, so the fans would shut off when the control air is bled off at night. For digital control systems, automatic off-hour control can be done in software at essentially no cost.

If the VAV boxes had electric duct heaters interlocked to operate when the fan energizes, then automatic controls would be required if the sum of the fan and duct heater power requirement exceeds 2 kW.

Example 4-G Time Controls – Equipment Room Cooling Unit

Q

An air conditioner serving an elevator equipment room in an office building is controlled by a thermostat that cycles the indoor supply fan and the compressor on calls for cooling. Does this unit need time controls so that it shuts off when the building is unoccupied at night?

A

No. The equipment must be maintained at a given temperature at all times, and thus qualifies for Exception a). Furthermore, when the elevators are inactive at night, the air conditioner will automatically shut off since there is no load in the space.

Example 4-H Off-Hour Isolation Controls – Floor-by-Floor System

Q

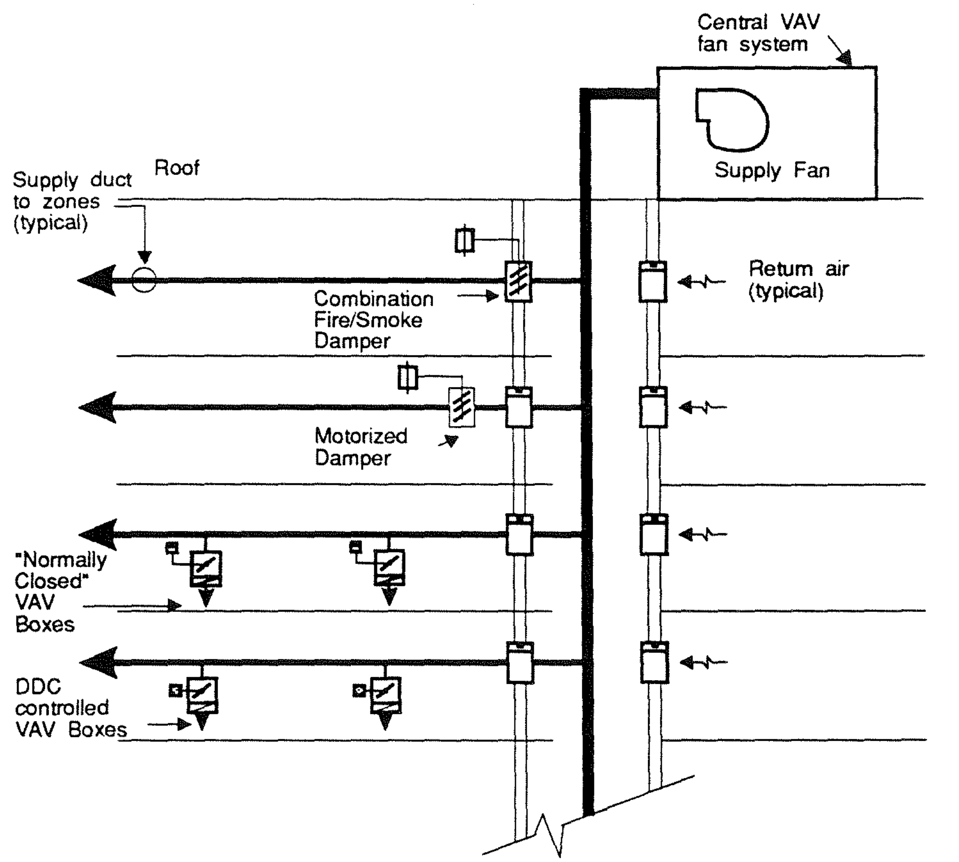
A speculative office building is designed to have an air handling system on each floor. What off-hour isolation provisions are required?

A

If the floors are less than 25,000 ft^2 of conditioned area, then each floor may be considered an isolation zone. Each fan system, and associated zone level heating systems, must be able to operate on a different time schedule.

If the floors are larger than 25,000 ft^2 and expected to be occupied by different tenants operating on different schedules, the system will have to be broken into more than one isolation zone. See discussion for ideas how this might be accomplished.

Figure 4-D Isolation Methods for a Central VAV System
(from ASHRAE Standard 90.1- 1989 User's Manual)



Each isolation area must include individual automatic time controls as if it were a separate HVAC system. This will allow each isolation zone to automatically operate on different time schedules.

Figure 4-D shows a schematic riser diagram of a central VAV fan system serving several floors of a building, each assumed to be less than 25,000 ft^2. Isolation of each floor is required if they are to be occupied by tenants that can be expected to operate on different schedules, or if tenant schedules are unknown. Isolation of floors or zones may be easily accomplished by any one of the methods depicted schematically in Figure 4-D:

- On the lowest floor, individual zones are controlled by direct digital controls (DDC). If the DDC software can be programmed with a separate occupancy time schedule for each zone or for a block of zones, isolation can be achieved without any additional hardware. The boxes are simply programmed to shut off or control to setback setpoints during unoccupied periods.
- On the next floor up, zone boxes are shown to be "normally closed," which means when control air or control power is removed, a spring in the box actuator causes the box damper to close. This feature can be used as an inexpensive means to isolate individual tenants or floors. The control source to each group of boxes is switched separately from other zones. When the space is unoccupied, the control source is shut off, automatically shutting off zone

boxes. A separate sensor in the space can restore control to maintain setback or setup temperatures.

- On the next floor up in Figure 4-D, isolation is achieved by simply inserting a motorized damper in the supply duct.
- On the top floor, the cost of this damper is saved or reduced by using a combination fire/smoke damper at the shaft wall penetration. Smoke dampers are often required by life safety codes to control floor air flow for pressurization. These dampers may serve as isolation devices at virtually no extra cost, provided they are wired so that life safety controls take precedence over off-hour controls. (Local fire officials generally allow this dual usage of smoke dampers and often encourage it since it increases the likelihood that the dampers will be in good working order when a real life safety emergency occurs.)

Note that on all floors in Figure 4-D, shut-off is not shown on floor return openings. This is because the wording of the Code requires that only "*the supply of cooling*" be shut off. In addition, with a plenum return system, the amount of air drawn off an unconditioned floor will be negligible compared to the occupied floors that have positive air supply since the latter will be pressurized.

Note also that a positive means of zone shut off or setback is required. Shut-off VAV boxes (boxes with no minimum volume setting) cannot be assumed to automatically close during unoccupied periods due to low loads since there may be 24 hour internal loads (such as PCs, idling copy machines, or emergency lighting) and envelope loads are continuous.

Simply providing means for central system zone isolation does not end the design task. *Central equipment must be capable of operating at the very low loads that can be expected when only one isolation zone is operating.*

Experience has shown that almost any fan with a variable speed drive for static pressure control can operate stably to zero flow. This is true even for large centrifugal fans which will eventually pass into the surge region of their fan curves as load reduces, provided this occurs when the fan is operating below about 50% speed and static pressure setpoints are less than about 2 inch wg. Under these conditions, fan power is reduced to the point where surge pulsations will generally have too little energy to cause damage.

Example 4-I Off-Hour Isolation Controls – Fan-Coil System

Q

A system consists of fan-coils for each zone piped back to a central chiller. What isolation devices are required?

A

Assuming the fan-coils serve spaces that operated on different time schedules, they would have to be grouped into isolation zones. Each isolation area would need a timeclock interlocked to control the fan-coils. Because the supply of cooling to each space will stop when the supply fan is shut off, the flow of chilled water to each fan-coil or to each isolation area need not be shut-off independently of other areas, although this is desirable. The central chiller and associated pumps would be interlocked in parallel with each isolation area control so they would operate when any area is occupied. In Hawaii, chilled water flow to fan-coils should always be shut off when fan is not running to avoid excessive condensation.

Large axial fans with variable pitch blades may also be able to operate at low flows without over-pressurizing ductwork. Fan curves at minimum blade pitch should be reviewed to be sure shut-off pressures are below duct design pressures.

Where fans cannot be selected to operate safely at low loads, large fans can be broken into smaller fans in parallel with operation, staged so only one fan operates at low loads.

The same considerations can apply to central chiller plants. The plant must be able to operate at low loads for extended periods. If frequent chiller cycling is not acceptable, either multiple or staged chillers can be used. As a last resort, hot-gas-bypass can be used to maintain stable low load operation, but this can significantly increase energy costs and should only be used if installation cost budgets prohibit the use of multiple staged chillers.

Humidity Control

Systems with active means to provide humidification or dehumidification must be controlled by a humidistat. For dehumidifiers, the controller must be capable of being set up to 60%. It is recommended (but not required) that the designer consider the use of heat recovery, such as condenser or desuperheater, when dehumidification requires the reheating of air that was previously cooled.

Ventilation

Except where additional outdoor air intake is required to make up process exhaust systems or other special requirements, HVAC systems must be capable of supplying only the minimum outdoor air for ventilation in accordance with the Ventilation Rate Procedure (Section 6.13) of ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality.*

Although energy conservation is the aim of the Code, it must not override requirements for comfort and particularily for health. Therefore, the Code does not limit outdoor air intake to Standard 62 minimum levels; it simply requires that systems have the capability to operate at those levels. This seemingly loose requirement is because many experts feel higher rates are required for adequate indoor air quality. The emission and control of indoor air pollutants is extremely complicated and there are few comprehensive technical reports or reference studies to use as design guidelines at this time.

If designed to supply higher rates than the minimum prescribed by Standard 62, systems must be easily adjusted to supply only the minimum rate at some time in the future. Acceptable means of adjustment include varying fan speed by changing sheaves or adjusting movable dampers. While adequate indoor air quality should take precedence over energy conservation, the energy consequence of achieving this goal by dilution with outdoor air must not be overlooked. Conditioning outdoor air is extremely energy intensive and outside air intake for ventilation should be minimized.

While not required by the Code, the following guidelines are recommended to reduce the energy usage associated with ventilation outside air intake.

Source Control

The best way to minimize energy usage and still maintain high quality indoor air conditions is to minimize the source of pollutants. This can be achieved by specifying materials for furnishings, carpeting, etc. that do not off-gas objectionable volatile organic compounds. Unfortunately, it may be difficult to do so at this time since little off-gassing data are available to the designer in product catalogues, and the exposure limits for most compounds in the non-industrial environment are not known.

If sources cannot be limited, they can often be controlled. For typical furnishings this may require air purging systems that remove off-gassing compounds when furnishings are first installed; off-gassing rates decrease exponentially and are usually small after a few months installation.

For persistent sources, such as blueprint (diazo) machines and large copy machines, exhaust hoods can be installed over the source to reduce the amount of pollutants that escape into the conditioned space.

Ventilation Effectiveness

Ventilation outdoor air must be effectively mixed with air in the occupied space. Poorly selected, sized, or placed air outlets can reduce ventilation effectiveness to as little as 50% (with 100% defined as perfect mixing) although this is unusual. To mitigate this problem, outdoor air intake rates are often increased, or overall circulation rates are increased (by using fan-powered mixing boxes or smaller supply air to room air temperature differences) to improve air outlet performance. Both of these options will increase energy usage unnecessarily.

Ventilation effectiveness can be improved with minimal energy impact by following the guidelines below:

- Use supply air outlets that have high aspiration ratios, such as slot diffusers or light troffer diffusers. The air pattern a few feet from a well designed outlet supplied with a small amount of cold (or hot) air can be identical to the pattern that results from a poor outlet supplied with a higher air quantity. In other words, ventilation effectiveness can be improved without arbitrarily increasing supply air quantities which unnecessarily increases fan energy.
- Distribute outlets well around each space; avoid using one large outlet when several small outlets will distribute air more evenly.
- Do not oversize outlets, which reduces their throw and aspiration ratio. This is particularly important for VAV systems which will operate at less than full flow most of the time.
- Locate returns where they will not short-circuit supply air. With properly sized outlets, the location of the return will generally not affect space mixing unless the return is located too close to the supply. Take extra care when using light fixtures for returns since they are often close to supplies and their location is not under the control of the HVAC designer; ensure that fixtures located close to supplies are blanked off.

Recent research ("Air exchange effectiveness of conventional and task ventilation for offices", *Healthy Buildings*, Preceedings of the ASHRAE IAQ Conference in Washington D. C., 1991) indicates that ventilation effectiveness with conventional ceiling supply and return grilles is typically 100% even when serving a space with five to six foot partitions. Based on this data, particularly if the above guidelines are followed, outdoor air ventilation rates need not be increased above minimum levels to account for ventilation effectiveness.

Intermittently Occupied Spaces

For spaces that have high peak occupancies but which are only intermittently occupied, such as ballrooms, meeting rooms, and theaters, vary outside air intake rather than constantly maintaining the high rates needed for peak occupancy.

Standard 62 allows even the peak ventilation rate for spaces occupied for only a short period to be reduced from the normal level. Where peak occupancy occurs for less than 3 hours, determine ventilation rates by the average occupancy or one-half the peak occupancy whichever is larger, over the duration of system operation. Always use this allowance for movie theaters, ballrooms, conference rooms, etc. where applicable.

For spaces that are people load dominated, those where the cooling load from people is the largest load component at design conditions, such as movie theaters or ballrooms, use of a VAV supply system that varies supply air with the cooling load and therefore indirectly with people density, can provide effective ventilation demand control at no added cost.

For other applications, a control system that modulates outdoor air intake to maintain a maximum space CO_2 concentration may be considered. CO_2 concentration is indicative of indoor air quality for spaces whose primary sources of indoor air pollution are the occupants themselves.

Ventilation Through Transfer Air

For some spaces, Standard 62 allows the minimum ventilation supply air quantity to be met by transferring air from adjacent spaces that are over ventilated. For instance, a toilet room or conference room may be exhausted, with make-up air transferred from an adjacent occupied space that is supplied with sufficient outside air to meet the requirements of both spaces.

Standard 62 strictly allows this approach only for spaces that have exhaust air fans. But logically the concept could be extended to spaces that are supplied with air transferred from other spaces. This would for instance allow the plenum air supplied by fan-powered VAV boxes, to meet ventilation air quantities provided other spaces open to the return plenum, such as interior zones, were directly supplied with sufficient outside air to meet the requirements of all spaces.

Ventilation for Multiple Zone Systems

There is much confusion concerning how to properly control ventilation for central systems that serve multiple zones, each with varying, and possibly conflicting, air conditioning load and ventilation requirements. The system can only supply a given percentage of outdoor air to all spaces. But one space may require a high air flow rate because it has a high cooling load, while another may receive only a small rate due to low cooling loads. At the same time, the ventilation requirements of the two spaces may be the opposite; the space with the high cooling load may require only a small amount of outdoor air, such as a perimeter office with large windows, while the lightly loaded space may require high outdoor air rates, such as an interior conference room. The situation is further complicated for VAV systems where the supply air rates are constantly changing.

To practically address this problem with energy efficiency, the following approach is suggested for central, multiple zone systems, particularly VAV systems:

Transfer Air

Use the transfer air approach discussed above for zones that require high ventilation rates, such as conference rooms. Use transfer exhaust fans or fan-powered mixing boxes. Base peak air quantities on one-half the design occupancy if the space is typically occupied at peak for less than 3 hours.

Dilution Approach

Use the dilution approach detailed in section 6.1.3.1 of Standard 62 to determine the design peak quantity of outdoor air, assuming all zones are at design conditions. The dilution equation from Standard 62 can be expressed as:

$$V_{ot} = \frac{V_{on}}{(1 + X - Z)} \tag{4-A}$$

$$X = \frac{V_{on}}{V_{st}}$$

$$Z = \frac{V_{oc}}{V_{sc}}$$

where

V_{ot} = the required overall outdoor air intake

V_{on} = the sum of outdoor air intakes required for all zones served by the system

X = the uncorrected fraction of outdoor air

Z = the fraction of outdoor air for the "critical zone"

Critical Zone = the zone with the highest value of Z

V_{st} = the total supply volume of central fan (outdoor air plus recirculated air)

V_{oc} = the outdoor air supply required to the critical zone

V_{sc} = the total supply air volume to the critical zone

The "critical zone" is selected from those zones that are *not* ventilated with transfer fans; conference rooms, for example, would not be used as the critical zone. The typical critical zone would be an interior office space which has a low cooling load but an occupant density similar to other zones. The dilution equation will then establish the minimum ventilation rate required for the building. For VAV systems, this same rate is used regardless of actual system supply volume since dynamic, real-time calculation of ventilation rate is impractical. CO_2 control systems are recommended to reduce this rate when the building is only partially occupied.

Note that if one completely embraces the transfer air concept described above, one need not use the dilution equation; the overall outdoor air rate required would simply be the sum of the outdoor air rates required for each space. This is because any excess air supplied to one space is transferred via the return system to other zones that may be under ventilated.

VAV Minimum Setpoint

Proper setpoints for minimum supply air volumes on VAV boxes are a controversial issue. There are several design approaches that have been used successfully:

- If boxes are fan-powered and the fan operates either continuously (series type) or when primary air volumes are reduced to below the Standard 62 ventilation rate (parallel type), then no primary air minimum volume need be maintained at all, provided the minimum outdoor air rate for the whole system is maintained. This approach relies on the transfer air concept that is only partially addressed in Standard 62.
- For those who only partially agree with the transfer air concept, primary air minimum volume settings should be equal to the minimum outdoor air flow rate required by Standard 62 for the zone. This ignores the fact that the primary supply air may not be 100% outdoor air. Again, maintain the overall minimum for the system back at the main fan.

- For those who do not believe in the use of transfer air at all, set minimum rates using the same concept used to develop the dilution equation above:

$$V_{zm} = \frac{V_{oz}}{Z} \tag{4-B}$$

where:

V_{zm} = the zone minimum VAV box setting

V_{OZ} = the zone minimum required outdoor air

Z = the critical zone ratio of outdoor air to overall supply air (as defined above)

This equation, which assumes that the dilution equation was used to establish the overall quantity of outdoor air, accounts for the dilution of return air to minimize volume settings.

The conservatism in using this approach can be seen by applying it to the critical zone: the minimum volume would be equal to the maximum design volume, which means the zone supply air would be constant volume. Some form of reheat would be required for temperature control.

A similar controversy surrounds the requirement for minimum volume settings in interior spaces. Many engineers feel that minimum settings are not required because the presence of people and lights in a space will cause the VAV box to open enough to satisfy ventilation rates. In fact, if a minimum is set, the space would be overcooled when the loads from people and lights were less than those at peak design conditions, unnecessarily wasting energy and causing discomfort. A more conservative approach would be to set minimum volumes as above and to install reheat coils to prevent overcooling. This approach is obviously energy wasteful and more expensive.

The "correct" approach to ventilation control with VAV systems is not yet known. Some engineers will argue that the many successful applications of the less conservative approaches discussed above prove that they will result in adequate indoor air quality. Others, concerned with liability and the increasing litigation surrounding "sick buildings" choose the more conservative approaches. Extensive research is required to establish which is "correct."

If the designer selects a conservative approach, it is recommended that the system be designed to have the capability to operate that way only , but that the initial minimum volume setpoints and outside air quantities be set using the less conservative approaches which will minimize energy usage. Should this operation result in less than adequate indoor air quality, adjust the minimum VAV box settings and minimum outdoor air quantities upwards toward the more conservative levels until the situation is resolved. Make sure that the Owner understands this approach so that responsibility for the perceived "gamble" is shared.

Piping Insulation

Thermally insulate all piping associated with HVAC systems in accordance with Table 9-1, reprinted in this manual as Table 4-D.

The values in the Table 9-1 (or 4-D) are minimum thicknesses of insulation having a conductivity falling in the range listed, when tested at the mean rating temperature listed, for each fluid design temperature range category. These conductivities are typical of fiberglass and most elastomeric foam insulations.

Table 4-D Minimum Pipe Insulation (in.)[a]

	Insulation Conductivity		Nominal Pipe Diameter (in.)					
Fluid Design Operating Temperature Range °F	Conductivity Range Btu-in/h-ft 3°F	Mean Rating Temperature °F	Run outs[b] up to 2	1 and less	1-1/4 to 2	2-1/2 to 4	5 & 6	8 & up
Heating Systems (Steam, Steam Condensate, and Hot Water)								
Above 350	0.32-0.34	250	1.5	2.5	2.5	3.0	3.5	3.5
251-350	0.29-0.31	200	1.5	2.0	2.5	2.5	3.5	3.5
201-250	0.27-0.30	150	1.0	1.5	1.5	2.0	2.0	3.5
141-200	0.25-0.29	125	0.5	1.5	1.5	1.5	1.5	1.5
105-140	0.24-0.28	100	0.5	1.0	1.0	1.0	1.5	1.5
Domestic and Service Hot Water Systems[c]								
105 and Greater	0.24-0.28	100	0.5	1.0	1.0	1.5	1.5	1.5
Cooling Systems (Chilled Water, Brine, and Refrigerant)[d]								
40-55	0.23-0.27	75	0.5	0.5	0.75	1.0	1.0	1.0
Below 40	0.23-0.27	75	1.0	1.0	1.5	1.5	1.5	1.5

Notes:

[a] For minimum thicknesses of alternative insulation types, see 9.3(g)(2).

[b] Runouts to individual terminal units not exceeding 12 ft in length.

[c] Applies to recirculating sections of service or domestic hot water systems and first 8 ft from storage tank for non-recirculating systems.

[d] The required minimum thicknesses do not consider water vapor transmission and condensation. Additional insulation, vapor retarders, or both, may be required to limit water vapor transmission and condensation.

Example 4-J Insulation – Chilled Water Return Piping

Q

A chilled water system is designed for a chilled water supply temperature of 44°F with a 14°F range. Is insulation required on the return piping?

A

No. Chilled water return temperature will be 58°F at *design* conditions, so this piping would fall under exception b) and no insulation is required by the Code. However, return water temperatures will often be lower at part load, and will often be lower than ambient dew point temperatures as well. Therefore, while the Code does not require insulation, minimal insulation should be provided from a practical standpoint to prevent condensation, and it may be cost effective since it reduces chiller load.

If other insulation products are to be used, such as cellular glass or calcium silicate, then the thicknesses listed in Table 9-1 (or 4-D) must be adjusted by the following equation:

$$T = PR[(1+\frac{t}{PR})^{K/k} - 1] \quad (4\text{-}C)$$

where

T = the minimum insulation thickness, in inches, for alternative material with a conductivity K

t = the insulation thickness, in inches, from Table 9-1 (or 4-D)

PR = the actual pipe outside radius, inches. This is generally *not* equal to half of the nominal pipe diameter; except for piping 14 in. and larger, actual OD will be larger than the nominal diameter and depends on the piping material selected. Actual ODs can be found in standard piping tables. An abridged version for copper and steel is shown in Table 4-E.

K = the conductivity of alternative material, in Btu-in/(h-ft^2-°F), when measured at the mean temperature indicated in Table 9-1 (or 4-D) for the applicable fluid design temperature range

k = the lower value of the conductivity range listed in Table 9-1 (or 4-D) for the applicable fluid design temperature range

Exceptions

Insulation is not regulated in the following cases:

a) Piping that is factory installed within equipment that is tested and rated in accordance with Section 10.3 of the Code. The intent here is to exempt piping within equipment whose energy performance is tested, and piping losses are ostensibly accounted for in the ratings.

Table 4-E Copper and Steel Pipe Sizes
(from ASHRAE Standard 90.1- 1989 User's Manual)

	Copper, (all wall thicknesses)		Steel, (all wall thicknesses)	
Nominal Pipe Size, inches	Actual Diameter, inches	Actual Radius, PR, inches	Actual Diameter, inches	Actual Radius, PR, inches
1/4	0.375	0.188	0.54	0.270
3/8	0.500	0.250		
1/2	0.625	0.313	0.84	0.420
5/8	0.750	0.375		
3/4	0.875	0.438	1.05	0.525
1	1.125	0.563	1.32	0.658
1-1/4	1.375	0.6875	1.66	0.830
1-1/2	1.625	0.813	1.90	0.950
2	2.125	1.063	2.375	1.188
2-1/2	2.625	1.313	2.875	1.438
3	3.125	1.563	3.50	1.750
4	4.125	2.063	4.50	2.250
5			5.56	2.782
6			6.625	3.313
8			8.625	4.313
10			10.75	5.375
12			12.75	6.375

Example 4-K Calculation of Pipe Insulation Thickness – Cellular Glass

Q

Cellular glass piping insulation is proposed for 10" chilled water lines. (This insulation material is often preferred since it is very durable and will not absorb water like fiberglass, which effectively destroys its insulating properties. There is then less concern about the quality of insulation vapor retarder and weather proofing.) The design chilled water supply temperature is 44°F to 54°F. What thicknesses are required?

A

From the manufacturer's catalog, cellular glass has a conductivity of 0.33 Btu-in/(h-ft^2-°F) at 75°F mean temperature. The minimum insulation thickness using Equation 9-1 (or Equation 4-C) is:

$$T = 5.375[(1 + \frac{1.0}{5.375})^{0.33/0.23} - 1] = 1.49 \text{inch}$$

Where:

PR	=	5.375 (from Table 4-E for steel pipe)
t	=	1.0" (from Table 9-1 or 4-D)
K	=	0.33 (from manufacturer's catalogue)
k	=	0.23 (from Table 9-1 or 4-D)

The next largest standard size is 1-1/2 in. insulation which is the thickness specified in this application.

b) Piping conveying fluids that have design operating temperatures between 55°F and 105°F, such as typical condenser water piping

c) Piping that conveys fluids that have not been heated or cooled through the use of fossil fuels or electricity. This exception is intended to cover gas piping, cold domestic water piping, waste and vent piping, rain water piping, etc. which may carry fluids with operating temperatures outside the 55°F to 105°F range but for which no energy was consumed to bring the fluids to these temperatures. While insulating such piping will have no energy impact and is not required, it may be desirable in some cases, and possibly required by building codes, to prevent condensation.

d) Where it can be shown that heat gain or heat loss to or from the piping will not increase building energy costs. Examples of piping falling into this exception are condensate drains, liquid and hot gas refrigerant lines on AC units, and liquid lines on heat pumps.

Duct Insulation

Ductwork and air plenums must be thermally insulated in accordance with Table 9-2 of the Code (reprinted in Table 4-F).

Caution should be exercised if "cold-air" systems are used. They may supply air 10 to 15 degrees F colder than the usual supply air temperature. Even in the usual temperature range, condensation can occur if insulation is unduly compressed or if there are openings or gaps in the vapor regarding envelope.

Requirements are divided into two primary categories, one for ducts that are outdoors exposed to weather, and one for ducts that are either in unconditioned spaces (enclosed but not within the building envelope) or in conditioned spaces (within the building envelope). This second category is extended by footnote *g* to Table 9-2 to include semi-enclosed spaces such as vented attics and crawl spaces.

Table 4-F Minimum Duct Insulation[a]

Duct Location	Cooling[b] Temperature Difference (F)	Insulation R-Value[d] (h-ft²-°F)/Btu
Exterior of building		
	All	8.0
Inside of building envelope or in unconditioned spaces[g]		
$\Delta T^e \leq 15$	---	None required
$40 \geq \Delta T^e > 15$	---	3.3
$\Delta T^e > 40$	---	5.0[f]

See notes for Table 9-2 in the Code.

Table 4-G R-Values for Common Duct Insulation Materials

(from ASHRAE Standard 90.1- 1989 User's Manual)

R-Value (hr-°F-ft²)/Btu	Nominal Thickness	Typical materials
3.3	1-1/2 in.	1/2 to 1-1/2 lb/ft³ fiberglass duct wrap
	1 in.	3/4 to 3 lb/ft³ fiberglass duct liner
	1-1/2 in.	1/2 lb/ft³ fiberglass duct liner
	1 in.	fibrous glass ductboard
	1 in.	insulated flexible duct
5.0	3 in.	1/2 lb/ft³ fiberglass duct wrap
	2 in.	3/4 to 1-1/2 lb/ft³ fiberglass duct wrap
	1-1/2 in.	3/4 to 2 lb/ft³ fiberglass duct liner
	1 in.	3 lb/ft³ fiberglass duct liner
6.5	3 in.	1/2 to 1-1/2 lb/ft³ fiberglass duct wrap
	2 in.	3/4 to 1-1/2 lb/ft³ fiberglass duct liner
	1-1/2 in.	2 to 3 lb/ft³ fiberglass duct liner
8.0	4 in.	1/2 to 3/4 lb/ft³ fiberglass duct wrap
	3 in.	1 to 1-1/2 lb/ft³ fiberglass duct wrap
	3 in.	3/4 to 1 lb/ft³ fiberglass duct liner
	2 in.	1-1/2 to 3 lb/ft³ fiberglass duct liner

The insulation requirements for enclosed ducts depends on a value of ΔT, defined as the temperature difference between the air conveyed in the duct and the ambient air surrounding the duct, both at design conditions. In many cases, determining these temperatures will require some judgment on the part of the designer, particularly for ambient temperatures of unconditioned spaces. A rough estimate of supply air, return air and unconditioned space temperatures will usually suffice since each requirement is for a broad range of temperature differences.

The R-values listed in Table 9-2 (4-F) are for the insulation material as installed, excluding air film resistances, but including the effect of the compression of duct wraps as they are typically installed. Duct wraps are generally assumed to be compressed to 75% of their nominal thickness when they are installed. Material conductivity is as measured in accordance with ASTM C518-85 at 75°F mean temperature. Common materials that meet the R-value levels in Table 9-2 (4-F) are shown in Table 4-G.

Exceptions

The following applications need not meet the requirements of the Table 9-2 (4-F):

a) Plenums and casings that are factory installed and an integral part of equipment rated in accordance with Section 10.4. Like factory installed piping insulation, this exception is intended to apply to casings around tested equipment, the energy losses through which are accounted for in the energy performance tests and ratings. Although they are not always included in performance testing, optional casings should also be exempted from insulation requirements if they are insulated to the same extent as the equipment to which they are attached. This is a practical requirement since designers seldom have the option to specify casing insulation levels.

b) Where it can be shown that heat gains or losses to or from the plenum or ductwork will not increase building energy costs. Most exhaust ductwork falls under this exception, although some process exhaust ducts conveying hot (or cold) gasses would have to be insulated where they pass through conditioned spaces.

Default Duct Insulation Values

For supply and return ducts inside of the building envelope or in unconditioned spaces, application of Table 9-2 (4-F) is based on the determination of a ΔT. Design air temperatures for supply ducts will also vary from one system to another, but typically are in the range of 55°F to 60°F for cooling. Using these temperatures, default values of ΔT for a variety of supply and return duct locations were calculated and are presented in Table 4-H. In Table 4-H the default ΔT (and consequently the default minimum required insulation R-value) are determined by the design outdoor-air dry-bulb temperature. For buried ductwork use the design ground temperature to determine the insulation requirements.

Table 4-H Default ΔTs and R-Values for Supply and Return Ducts in the Building Envelope or in Unconditioned Spaces[a]

(from ASHRAE Standard 90.1- 1989 User's Manual)

			Cooling[b]	
Duct Type	Location	ΔT ≤ 15 none required	40 ≥ ΔT > 15 R-3.3	ΔT > 40 R-5.0
Supply	Ventilated attic		<85	≥85
	Unvented attic		<80	≥80
	Shaft or crawlspace		<95	≥95
	Plenum		all	
	Buried[c]	<70	≥70	
Return	Ventilated attic	<82	82-107	^{3}107
	Unvented attic	<77	77-102	^{3}102
	Shaft or crawlspace	<92	92-117	^{3}117
	Plenum wall	<92	92-117	^{3}117
	Buried[d]	all		

Notes:

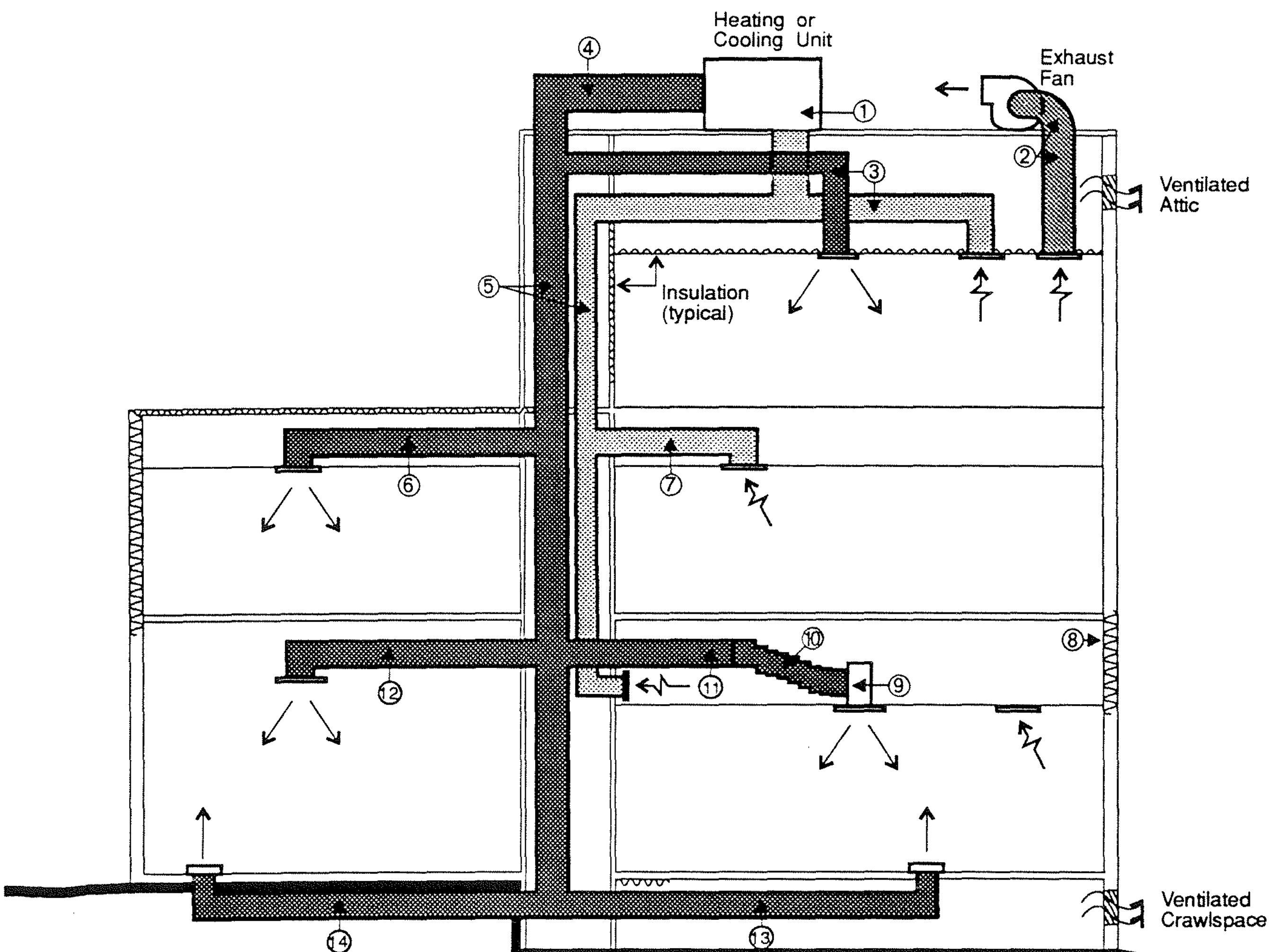
[a] Assumptions are as follows: 55°F/77°F cooling supply/return temperatures; ventilated attics run 10°F warmer than outside air temperatures during peak cooling; unvented attics run 15°F warmer than outside air temperatures during peak cooling; shafts and crawl space temperatures are equal to outside air temperature during peak cooling;

[b] Entries in the table are the design cooling dry-bulb temperatures (°F). The 2.5% values from the ASHRAE Fundamentals Handbook should be used.

[c] Buried ducts and trench ducts are given in reference to ground temperatures (°F). Average ground temperatures can be taken as 74° F.

Figure 4-E Duct Insulation

(from ASHRAE Standard 90.1- 1989 User's Manual)



KEY

1. Insulation of unit casing
2. Exhaust
3. Supply and return in vented attic
4. Supply on exterior of building
5. Supply and return in shaft
6. Supply in unvented attic
7. Return in indirectly conditioned ceiling space
8. Exterior wall of return plenum
9. Supply outlet in plenum
10. Supply runout in plenum
11. Supply in plenum
12. Supply in conditioned space
13. Supply in vented crawlspace
14. Buried supply

Figure 4-E identifies the primary duct configurations that have requirements from Table 9-2 (4-F). The insulation requirements for each duct location identified in Figure 4-E are described in the following paragraphs:

1. Unit Casings and Plenums

Factory installed insulation which is part of the HVAC equipment is covered through the minimum equipment efficiencies of Article 10 and does not have requirements in this section (exception a). This includes equipment casings and plenums. This exception does not hold for built-up systems with field-fabricated plenums. These systems must be insulated per the requirements for ductwork in this section: built-up penthouses on the roof must meet the insulation requirements for ductwork on the exterior of the building, perimeter mechanical rooms which are used as mixing plenums must have exterior walls insulated to meet the requirements for return ductwork on the exterior of the building, etc.

2. Exhaust Ductwork

In general, exhaust ductwork need not be insulated since insulation will have no impact on building energy usage (exception b).

3. Supply and Return Ducts in Vented Attic

These ducts are located in an attic which is vented to the outside. Footnote *g* to Table 9-2 (4-F) specifies that crawl spaces and attics, vented or otherwise, are to be considered unconditioned spaces for the purpose of determining duct insulation requirements. A vented attic will generally run 5°F to 20°F warmer than the outside air temperature during peak cooling, and be close to the outside air temperature during peak heating.

Default Supply Insulation. In most cases, supply ducts must be insulated with a minimum of R-5.0. They may be insulated with R-3.3 where they serve a cooling-only system and the design cooling dry-bulb temperature is less than 85°F.

Default Return Insulation. The required insulation for return ducts varies as follows: no insulation is required for cooling-only systems with design cooling dry-bulb temperatures less than 82°F; R-3.3 is required for heating systems with a design heating dry-bulb temperature greater than 33°F or cooling systems with a design temperature between 82°F and 107°F; R-5.0 is required with heating systems where the design temperature is less than 33°F or cooling systems with the design temperature greater than 107°F.

4. Supply and Return Ducts on Exterior of the Building

Exposed ductwork insulation requirements are determined by local weather conditions. In all cases the minimum insulation R-value is determined by the cooling degree days base 65°F (CDD_{65}) for ducts serving cooling systems (supply and return) and the heating degree days base 65°F (HDD_{65}) for ducts serving heating systems (supply and return). These weather parameters can be found in Appendix C of the Standard.

5. Supply and Return Ducts in Shaft

These ducts are located in unconditioned space similar to case 3 above. However, this wall cavity will not have the extreme temperatures of the attic since the space is not vented to the outdoors and has a minimal roof load. Where design temperatures for the shaft space are not available from load calculations, one can assume that at design conditions, the shaft temperature is near outside conditions at both cooling and heating peaks.

Default Supply Insulation. In most cases, supply ducts must be insulated with a minimum of R-5.0. They may be insulated with R-3.3 where they serve a cooling-only system and the design cooling dry-bulb temperature is less than 95°F.

Default Return Insulation. The required insulation for return ducts varies as follows: no insulation is required for cooling-only systems with design cooling dry-bulb temperatures less than 92°F; R-3.3 is required for heating systems with a design heating dry-bulb temperature greater than 33°F or cooling systems with a design temperature between 92°F and 117°F; R-5.0 is required with heating systems where the design temperature is less than 33°F or cooling systems with the design temperature greater than 117°F.

6. Supply (and Return) Ducts in Unvented Attic

Here the ducts are located within an unventilated attic. The temperature within the attic is often determined in load calculations. If not, it must be estimated. The attic temperature will be higher than space temperatures due to solar gains on the roof and heat from recessed light fixtures. An unvented attic will generally run 15°F to 30°F warmer than the outside air temperature during peak cooling, and be close to the outside air temperature during peak heating.

Default Supply Insulation. In most cases, supply ducts must be insulated with a minimum of R-5.0. They may be insulated with R-3.3 where they serve a cooling-only system and the design cooling dry-bulb temperature is less than 80°F.

Default Return Insulation. The required insulation for return ducts varies as follows: no insulation is required for cooling-only systems with design cooling dry-bulb temperatures less than 77°F; R-3.3 is required for heating systems with a design heating dry-bulb temperature greater than 33°F or cooling systems with a design temperature between 77°F and 102°F; R-5.0 is required with heating systems where the design temperature is less than 33°F or cooling systems with the design temperature greater than 102°F.

7. Supply and Return Ducts in Indirectly Conditioned Ceiling Space

This case is similar to case 6 but the ceiling space temperatures will be essentially equal to space temperatures for heating and slightly higher than space temperatures for cooling due to recessed light fixture heat gains. In general no insulation will be required on either supply or return.

8. Exterior Wall of Return Plenum

In this case the ceiling space is being used as a return plenum. The exterior walls of the space are effectively return duct walls exposed to the outside. This wall must be insulated to the more restrictive requirement of either Article 8 or the requirements for ducts located in the exterior of the building from Table 9-2 (4-F). These latter requirements are discussed in case 4 above.

9. Supply Outlet in Return Plenum

The plenum surrounding the air outlet is part of the supply duct system and therefore must be insulated the same as the supply ducts (case 11 below).

Default Supply Insulation. From Table 4-H, supply ducts must be insulated with a minimum of R-5.0 if they are used for heating, and they may be insulated with R-3.3 where they serve a cooling-only system. Generally, most supply plenums are insulated with only 1/2" of internal liner. Additional insulation would be required to meet the requirements of the Code. Enforcement bodies are encouraged to waive the requirements of this additional insulation for practical considerations.

10. Supply Runout in Return Plenum

Per footnote *f* to Table 9-2 (4-F) a runout of up to 10 feet to a terminal device (supply outlet or VAV box) need only be insulated with R-3.3. This is intended to allow standard flexible duct with 1" insulation (about R-4.0) to be used. Flexible duct with 2" insulation is not commonly available. This exception holds even if the supply ducts are required to have R-5.0 insulation.

11. Supply Ducts in Return Plenum

For supply ducts located in a return plenum, the ΔT is the difference between the supply and return temperatures. In general the temperature in a return plenum will be 1°F to 2°F warmer than the space temperature due to heat from the lights.

Default Supply Insulation. From Table 4-H, supply ducts must be insulated with a minimum of R-5.0 if they are used for heating, and they may be insulated with R-3.3 where they serve a cooling-only system.

12. Supply and Return Ducts in Conditioned Space

Per exception *b*, supply and return ducts located in the conditioned space do not require insulation. From a practical viewpoint, insulation may be desirable on cooling ducts to prevent condensation if the duct passes near local areas of high humidity as might occur in a kitchen. For typical spaces, condensation will generally not occur even at very low supply temperatures since the space relative humidity will be lowered correspondingly by the dry air supply.

13. Supply and Return Ducts in Vented Crawl Space

This is similar to the case of ducts in a vented attic (case 3 above). Because the space is vented and unlikely to experience strong solar loads, crawl space temperatures will be very close to the outdoor temperature.

Default Supply Insulation. In most cases, supply ducts must be insulated with a minimum of R-5.0. They may be insulated with R-3.3 where they serve a cooling-only system and the design cooling dry-bulb temperature is less than 95°F.

Default Return Insulation. The required insulation for return ducts varies as follows: no insulation is required for cooling-only systems with design cooling dry-bulb temperatures less than 92°F; R-3.3 is required for heating systems with a design heating dry-bulb temperature greater than 33°F or cooling systems with

Example 4-L Insulation Required for Pipes and Ducts in Conditioned Spaces

Q

A VAV system supplies cooling to exterior zones and interior zones in a building that has no ceilings. The supply ducts run exposed through the interior spaces. Do ducts require insulation?

A

No. The VAV duct mains supply cooled air and are located over interior spaces that also require cooling. Heat gains or losses from the ductwork will therefore not affect energy usage and thus fall under exception (b). Zone ducts also need not be insulated since they are located in the spaces served.

Example 4-M Leakage Testing of Ducts – 3 in.wg

Q

A duct system is designed to operate at a maximum operating pressure of 3 in.wg, but to reduce radiated noise levels, the engineer has specified that ducts be constructed to the SMACNA requirements for 6 in. operating pressure. What are the testing requirements for this ductwork?

A

The Code only requires testing based on the actual design operating pressure, not the pressure that the duct might actually be able to withstand. In this case, no testing is required since the design static pressure does not exceed 3 in..

Example 4-N Leakage Testing of Ducts – 4 in. wg

Q

If previous example were changed so that design operating pressures were 4 in. instead of 3 in., at what pressure would the leakage tests be conducted, 4 in. or 6 in.?

A

The ductwork would be tested at 4 in. since this is the actual design operating pressure.

Example 4-O Duct Sealing Requirements – Flex Connections at VAV Box

Q

VAV boxes are connected to the medium pressure duct main (3 in. pressure class) with flexible duct. What are the sealing requirements at the flexible duct connections to the main and to the VAV box?

A

Since the operating pressure is higher than 1 in.wg, pressure sensitive tape may not be used alone to secure either end of the flexible duct. But tape may be used as a secondary sealant, with a draw-band or panduit strap used to provide the primary seal.

Table 4-I SMACNA Sealing Classes and Requirements

Seal Class	Sealing Requirements	Required for SMACNA Static Pressure Construction Class
A	All transverse joints, longitudinal seams, and at penetrations of the duct wall	4 in.wg and higher
B	All transverse joints and longitudinal seams	3 in.wg
C	Transverse joints only	2 in.wg and VAV systems down to 1/2 in. pressure class

a design temperature between 92°F and 117°F; R-5.0 is required with heating systems where the design temperature is less than 33°F or cooling systems with the design temperature greater than 117°F.

14. Supply and Return Ducts Below Grade

The amount of insulation required for ducts located below grade depends on the ground temperature. Ground temperature in Hawaii is usually near 74° F.

Default Supply Insulation. From Table 4-H, the required insulation for supply ducts varies as follows: R-3.3 is required for cooling ducts with design ground temperatures over 70°F; R-5.0 is required for heating ducts with design ground temperatures under 75°F.

Duct Construction

Ducts and plenums must be constructed in accordance with SMACNA HVAC Duct Construction Standards - Metal and Flexible, 1985.

In addition to the requirements of these SMACNA Standards, two more stringent measures are required for compliance with the Hawaii Model Energy Code.

Ductwork Operating in Excess of 3 inch wg

Ductwork designed to operate at static pressures in excess of 3 inches of water gage (in. wg, also called inches of water column, in. wc) must meet leakage limitations as follows:

- Ducts must be tested in accordance with the procedures outlined in Section 5 of the "SMACNA HVAC Air Duct Leakage Test Manual", 1985, with tests reported using forms equivalent to those outlined in Article 6 of that Manual.
- To reduce costs, the entire duct system need not be tested. Tests may be made for only representative sections provided these sections represent at least 25% of the total installed duct area for the tested pressure class.
- Tested duct leakage at a test pressure equal to the design duct pressure must meet Leakage Class 6. Leakage class, as defined in the SMACNA Test Manual referenced above, is:

$$C_L = \left(\frac{F}{P}\right)^{0.65} \tag{4-D}$$

where

C_L = the leakage class

F = the measured leakage rate in cfm/100 ft^2 of duct surface

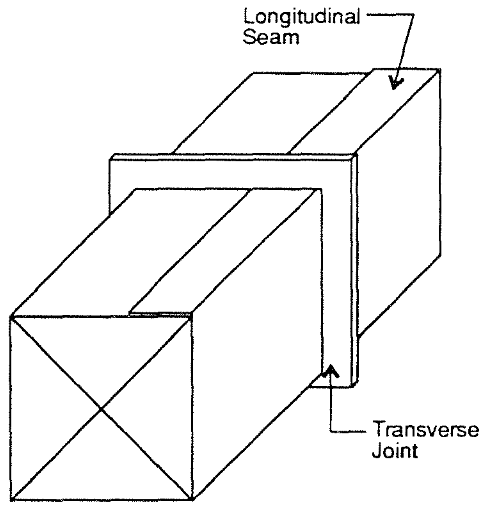
P = the static pressure used in the test

The leakage class according to this formula must be less than six when the test pressure is equal the design duct pressure class.

Sealing Requirements for Low Pressure Supply Ductwork

Supply ductwork designed to operate at static pressures from 1/4 in.wg to 2 in.wg inclusive that are located outside the conditioned space or in return air plenums must be sealed in accordance with Seal Class C as defined in the SMACNA manuals referenced above (either the HVAC Duct Construction Standards or the HVAC Air Duct Leakage Test Manual) and reprinted in Table 4-I. SMACNA manuals only require Seal Class C for ducts designed for 2 in. static pressure, plus ducts designed for 1 in. or 1/2 in. pressure classes if they are part of a VAV system. The Code extends this requirement to ducts designed for pressures as low as 1/4 in. In other words, virtually all HVAC supply ducts

Figure 4-F Ductwork Seams and Joints
(from ASHRAE Standard 90.1- 1989 User's Manual)



located outside the conditioned space or in return plenums must be sealed to Seal Class C.

Longitudinal seams are those parallel to the direction of air flow; spiral joints do not require sealing in any seal class. All other duct connections are considered transverse joints.

SMACNA does not limit the type of material used for sealing, except that exterior sealants must be specifically marketed for that application. But the Code does limit the use of pressure sensitive tape, which generally tends to peel with time and is therefore not a reliable sealant in the long run. Such tape may not be used as the primary sealant for ductwork designed to operate at static pressures 1 in.wg and higher.

Energy Recovery

Condenser heat recovery from air conditioning or refrigeration equipment is required for equipment with a capacity of 10 tons or larger or with a compressor motor greater than 15 hp when there is a water heater of a size greater than 75,000 Btu/h (fuel) or 12 kW (electric).

Heat recovery is not required by the Code if calculations show that it is not cost effective over the anticipated service life. Condenser heat recovery will generally be cost effective in Hawaii if there is a simultaneous need for the low grade heat such as water heating. This is typical of most hotels and condominiums with central water heating systems.

Operating and Maintenance Manuals

An operating and maintenance (O&M) manual that includes complete operating instructions and routine maintenance requirements must be provided to the building owner upon completion of construction.

The wording of this portion of the code is necessarily general because of the wide range of complexity of HVAC systems, from window air conditioners at one end to large central plants and air handling systems built up from several different types of equipment on the other. The intent of this section is to provide to the owner all information necessary to operate the system properly as a whole, not just each piece of equipment. If the system is very complex, requiring coordination among several pieces of equipment, the proper operating instructions, setpoints, etc. must be specified and included in O&M documents. This is usually done in control system design documents, such as system schematics and control sequence descriptions. For simple systems, such as small individual unitary equipment, a detailed system description and control schematic is not necessary to operate the system properly and thus need not be included in the O&M manual. ASHRAE Guideline 4, Guideline for Preparation of Operating and Maintenance Documentation for building Systems 91993) is a good source on the subject.

Testing and Balancing

HVAC systems must be tested and balanced to assure proper operation. ASHRAE's Guideline 1, Guideline for Commissioning HVAC Systems, (1989) is recommended for use in developing a comprehensive commissioning plan). Control systems must be tested, calibrated, and adjusted to proper operating setpoints.

Air and hydronic system balancing must be in accordance with the procedures published by the National Environmental Balancing Bureau (NEBB) or the Associated Air Balance Council (AABC), or an equivalent procedure.

Air System Balancing

Air systems must be balanced by first adjusting fan speed to meet design flow. Damper throttling alone may be used for balancing fans only under two conditions:

a) With motors 1 hp or smaller

b) Where throttling will increase fan power by no more than 1/3 hp above that required if the fan speed were adjusted. For instance, if the fan would require 5 hp if throttling were used to balance the system, but the energy demand would drop to 4.5 hp if operating at the correct speed for the required pressure drop, the fan speed would have to be adjusted since the difference exceeds 1/3 hp. The required horsepower can be estimated using the fan laws based on the actual system pressure drop and air flow at the original fan speed, measured at the initial system balance.

Hydronic System Balancing

Hydronic systems must be balanced by adjusting pump speed or by trimming the pump impeller to meet design flow requirements. Valve throttling alone may be used for final balancing only in the following cases:

a) Pumps with motors 10 hp or less.

b) If valve throttling results in an increase in pump power of no more than 3 hp above that required if the impeller were trimmed. (See discussion under exception b) above for air system balancing).

c) To reserve pump capacity to overcome future fouling in open circuit piping systems (cooling tower systems). Throttling losses may not exceed the pressure drop expected for future fouling.

Example 4-P Balancing Requirements – VAV Fan with VSD

Q

A fan serving a VAV system has a variable speed drive for static pressure control. During balancing its full load fan speed is found to be 20% faster than required. Do fan sheaves need to be adjusted or changed?

A

No. The variable speed drive will automatically reduce the fan speed as required to meet system static pressure requirements. In general, fan and pumping systems with variable speed drives are self-balancing provided their pressure setpoints are correct.

d) Where it can be shown that throttling will not increase overall energy costs. This may be the case for some condenser water systems since an increase in flow rate can reduce chiller energy usage enough to offset increased pump and cooling tower energy usage. A detailed analysis, including both part load and full load operating conditions, must be made.

Pump balancing requirements are less stringent than those for fans because the cost to adjust fan speed (which requires adjusting or changing a motor sheave) is relatively inexpensive while adjusting pump motor speed is generally impractical and removing the pump impeller, trimming it as required, then replacing it, is an expensive procedure cost justified only if energy savings are substantial.

Cooling of Unenclosed Spaces

In Hawaii, hotel lobbies, restaurants and many other spaces are left open to the mild climate and essentially unconditioned. Occasionally, spot cooling is provided for specific areas within these open spaces and this section of the Code addresses this application. The underlying intent of the requirement is to allow no more energy use for spot cooling of unconditioned space than would be the required if the space were enclosed and air conditioned. Cooling system capacity is therefore limited to 20 Btu/h-ft^2 or 400 Btu/h-occupant whichever is greater. These limits were selected to be representative of enclosed, air conditioned spaces.

The floor area that is cooled shall not extend beyond a boundary defined by the ceiling air diffusers or the throw of side wall diffusers. The space which is spot cooled must have a ceiling that extends at least ten feet from the boundary of the spot cooled area. The spot cooled area must also be bounded on at least one side to reduce wind velocities through the cooled area. Once the area is defined, the cooling delivered to the space may not exceed 20 Btu/h-ft^2.

If the 400 Btu/h per occupant method is used to establish the maximum cooling capacity, the occupancy load shall be based on the average intended occupancy and shall not exceed the Estimated Maximum Occupancy listed in Table 2 of ASHRAE Standard 62-1989.

Equipment Basic Requirements

Minimum Equipment Efficiencies

Equipment must meet or exceed the energy efficiencies shown in Tables 10-1 through 10-7 of the Code. These efficiencies must be measured in accordance with the rating standards as specified in those tables. Where there is more than one requirement for a given piece of equipment, the equipment must meet all requirements. Equipment ratings may be self-certified by the manufacturer or rated under a nationally recognized certification program. Field tests are *not* required.

Part-Load Performance

Actual equipment load profiles will vary by system type, building architecture, occupancy patterns and climate. Therefore it is only possible to determine performance at representative part–load conditions. While the results will not predict actual performance precisely, they can be used to compare different manufacturers and different equipment types in much the same way that EPA mileage ratings allow different cars to be compared even though actual mileage will vary.

There are three types of part–load descriptors used in the tables:

HSPF, AFUE, and SEER These are seasonal performance descriptors for DOE-covered heat pumps, gas furnaces and air conditioners, respectively, determined in accordance with DOE Test Procedure 10 CFR Part 430. These ratings are based on a typical weather profile and include the effects of equipment cycling. All products covered by the National Appliance Energy Conservation Act (NAECA) must be rated using these descriptors.

IPLV, or Integrated Part Load Value IPLV is a measure of part-load performance for some ARI–rated equipment with unloading capability. The units of IPLV are the same as those for the corresponding full–load descriptor; for instance an IPLV for an air conditioner has the same units as EER. IPLV is a weighted average of the steady-state equipment performance at several load conditions. An IPLV may contain up to three part–load efficiencies in addition to the full–load efficiency. Because measurements are steady-state, IPLV does not include the effects of equipment cycling; equipment is rated only at the part loading allowed by the equipment and its controls.

Low or high temperature ratings. Some equipment is rated at an off-design condition in addition to the standard full–load condition. While not actually a part-load condition (the equipment operates at full capacity) the off-design rating can give an indication of part–load equipment performance. Examples include high (47°F) and low (17°F) outside air temperature COP ratings for heat pumps and high (85°F) and low (75°F) temperature ratings for hydronic heat pumps. The ratings are steady-state and do not include the effect of equipment cycling.

Equipment with Multiple Functions

Equipment that is used for other purposes, such as service water heating, must meet the applicable requirements of *both* Article 10 and Article 11.

Omissions

Tables 10-1 to 10-7 of the Code cover the majority of equipment used in air conditioning systems. Equipment types that are not covered, such as absorption chillers, electric heaters, cooling towers and pumps, among others need not meet any efficiency level to comply with the code; omission does not imply that such equipment is precluded from usage.

Example 4-Q Part–Load Performance Requirements - Air Conditioner with a Single Compressor

Q

A 10-ton rooftop air conditioner has a single compressor with no unloading capability. Does this unit have to meet the IPLV requirement of Table 10-1?

A

No. IPLVs are determined by measuring performance at steady-state part-load conditions. If the equipment cannot operate at that condition without cycling, its steady-state performance cannot be measured. Thus for a single speed compressor with no cylinder unloading, IPLV requirements do not apply.

Example 4-R IPLV Calculation - Water Cooled Reciprocating Chiller

Q

How is the IPLV determined for a water-cooled reciprocating chiller with limited unloading capability?

A

For this product category IPLV is determined in accordance with ARI Standard 590 which requires that chiller performance be determined using the following equation:

$$IPLV = 0.17 \times EER_{100} + 0.39 \times EER_{75} + 0.33 \times EER_{50} + 0.11 \times EER_{25}$$

where

EER_n = EER at n% of full load

EER is measured at standard rating conditions with condenser water "relief" (2.5°F drop in condenser water temperature for each 10% drop in load). The weighting factors in the equation are based on an HVAC system with an air-side economizer serving a typical office building located in Atlanta. (To approximate performance for an actual application, the "Applied Part–Load Value" or APLV can be determined with the above equation using weighting factors customized for the actual building type and climate.)

If the unit cannot be operated at the 75%, 50% or 25% capacity levels due to limitations in its capacity control system, then the unit operation must be evaluated at other load points and the standard rating efficiencies determined by straight line interpolation between actual operating efficiencies. *Extrapolation is not allowed.* If a unit cannot operate below a standard rating capacity point, then the unit must be run at its minimum step of capacity at the condenser conditions corresponding to the standard rating capacity condition. The efficiency is then determined using the following equation:

$$EER_L = EER_M \times CD$$

where

EER_L = efficiency at part-load ratio L, Btuh/W

EER_M = measured efficiency at minimum part–load ratio M determined using condenser relief conditions for part-load ratio L, Btuh/W

CD = cycling degradation factor = 1.13 - 0.13 (L/M)

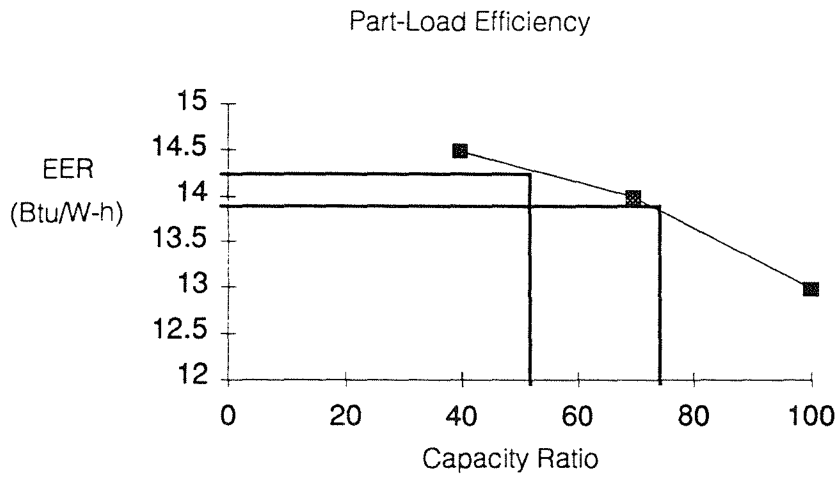
The chiller has three steps of unloading. Measured performance is indicated below:

Step	Capacity tons	Part-Load Ratio, %	Power kW	EER Btuh/W	CWS °F	CWR °F	CHWS °F	CHWR °F
3	123.0	100	92.3	13.0	85.0	94.7	44.0	54.0
2	85.5	69.5	59.6	14.0	77.4	84.1	44.0	51.0
1*	48.6	39.5	32.7	14.5	69.9	73.7	44.0	48.0
1	50.4	41.0	33.9	14.5	66.3	70.2	44.0	48.1

Example 4-P IPLV Calculation - Water Cooled Reciprocating Chiller (Continued)

The point labeled 1* is the performance at the minimum step of unloading using the standard condenser conditions for 25% load condition.

The rating points 1, 2 and 3 are plotted with straight lines between to determine the unit's performance at the 75% and 50% conditions:



From the graph (or by mathematical interpolation), the equipment EER at 75% and 50% load can be determined as 13.8 and 14.3 respectively.

Since the unit cannot operate at or below 25% load, performance at 25% load must be calculated by first measuring the performance at the lowest step of unloading, at the condenser water conditions appropriate for the 25% point (step 1* in the table above). CD is determined as:

$$CD = 1.13 - 0.13 \times 0.25 / 0.41$$
$$= 1.05$$

The EER_{25} is then calculated to be:

$$EER_{25} = EER_{(M=41\%)} \times CD = 14.5 \times 1.05 = 15.2$$

The results are summarized as follows:

Step	Part–Load Ratio, %	Weight Factor	EER, Btu/W-h
A	100%	0.17	13.0
B	75%	0.39	13.8
C	50%	0.33	14.3
D	25%	0.11	15.2
IPLV			14.0

The IPLV is 14.0, which is equivalent to a COP of 4.10 (14.0/3.413).

Example 4-S Process Conditioning - Computer Room

Q

A computer-room air conditioner serves a large central computer room. Does it have to meet any of the requirements of the Code?

A

There are two issues presented in this problem: the requirements for unlisted equipment and the exemption for equipment that serves process loads. Computer-room air conditioners are not listed in the tables of Article 10, and therefore have no minimum efficiency requirements to meet.

The scope of the Code does not include areas of buildings intended primarily for commercial processes, so equipment and systems which serve a computer room in general need not comply with any requirements of the Code. However, if the system also serves adjacent, non-process areas such as storage and offices, areas which are covered by the Code, then it must meet applicable requirements of Articles 9, 10 and 12. As a general rule, if 90% or more of the load for a specific piece of equipment is process conditioning, then that equipment is exempt from the scope of the Code.

Even if the unit need not comply, it would be cost effective to select a unit having very high efficiencies because it will operate so many hours of the year.

Field Assembled Equipment

If products from more than one manufacturer are used to produce a covered product with a cooling capacity less than 135,000 Btu/h, the performance of the combined system must be determined from data supplied by each manufacturer, and must meet the efficiency requirements for the applicable end-product category.

Mixed Manufacturers

For systems with capacities greater than or equal to 135,000 Btu/h, the individual refrigeration component (condensing unit) alone must comply with the requirements of Table 10-6 and the indoor unit is not regulated in this section. (Indoor fan energy may be regulated by Section 9.4(c) of the Code since exception (ii) to that section would not apply.) This requirement would apply for example to an indoor air handler used with an outdoor condensing unit to form a split system air conditioner.

Overall System and Equipment Energy Usage

When using the standard efficiency ratings established in this section take care in comparing different types of HVAC equipment. The ratings are sometimes at different rating conditions, such as groundwater–source heat pumps which are rated at 70°F compared to water-source heat pumps which are rated at 85°F. More importantly, the ratings may not include the energy used to operate auxiliary systems that may be required for the primary equipment to function in a complete system. For example:

- The efficiency ratings for water–cooled equipment cannot be directly compared to those for air–cooled equipment. Water–cooled equipment ratings do not include the energy used by required condenser water pumps and cooling tower fans while air–cooled package ratings include condenser fan energy.
- The ratings for condensing units cannot be directly compared to ratings for packaged or split system air conditioners. Condensing unit ratings do not include the energy used by indoor air handling fans.
- The efficiency of a chilled–water system cannot be compared to a unitary direct–expansion system using standard ratings. Chilled–water system

efficiency does not include the energy used by chilled water pumps and air handler fans.

Different types of equipment may be applied in many different ways and the manufacturer can only test the performance of equipment as it exists when it leaves the factory.

A fair comparison between different types of equipment, such as water– versus air–cooled equipment, requires knowledge of the auxiliary equipment needed for a complete system and the energy they use both at full and part load. Sometimes an energy analysis of the detail required by Article 13 is the only way to make an accurate comparison.

O&M Manuals

Operation and maintenance (O&M) manuals must be provided for all HVAC equipment installed in the building. Manuals must include preventive maintenance requirements and schedules, operating, tuning and calibration procedures, and the names of qualified service agencies.

Energy Management Basic Requirements

Introduction

Energy–conserving control systems are specified under the section that applies to the affected building component. For instance, required lighting control systems are specified in Article 6, HVAC control systems are specified in Articles 9 and 10, and service water heating system controls are addressed in Article 11 of the Code. This purpose of Article 12 is not to prescribe additional energy conserving controls, but to require measures that allow actual building energy usage to be better managed. As most business people know, in order to manage something, it must first be measured and quantified. This section prescribes minimum measures that will allow the building owner to measure or have the capability to measure overall building energy usage and individual equipment energy usage.

Energy Management Capability

Each separate building utility, such as gas or electricity, must be individually metered and the meter must be accessible to the building owner so that energy consumption (and demand if applicable) may be monitored. All buildings must be individually metered, except those less than 5,000 ft^2 gross floor area in a building complex which may be metered along with other buildings in the complex.

All HVAC equipment with energy input requirements at design conditions exceeding 20 kVA or 60,000 Btu/h must be arranged so that equipment input and output performance can be measured. This requirement is intended to provide the physical means to readily measure equipment performance, but permanent measuring devices, such as flow meters, ammeters, pressure gauges, etc., are not required.

Example 4-T Performance Measurement Requirements: Chilled Water System

Q

A central chilled water plant provides chilled water to several air handlers in a building. What is required to meet Section 12.3 of the Code?

A

The following devices would meet this section:

- Wiring must be accessible, in starter panels for instance, so that current can be measured to each piece of electrical equipment larger than 20 kVA. (This is standard on any design.)
- Thermometers and flow measuring devices, or at least test plugs for portable thermometers and pressure gauges, must be installed at the chilled water inlet and outlet to each air handler larger than 60,000 Btu/h capacity in order to measure actual flow rates and coil output.

Energy Management System Recommended

Energy management systems are recommended for buildings larger than 20,000 ft^2 gross area, but not required by the code. The following are examples of functions the energy management system might perform:

- Provide readings and retain daily totals for all electric power consumption and demand, and for energy consumption of other energy sources such as natural gas.
- Record, summarize and retain weekly totals of measured energy usage.
- Provide the time scheduling capabilities (9.3(d)) for HVAC and service water heating systems (11.3(f)).
- Provide the capability to reset HVAC control loops for HVAC systems (9.4(e)).
- Monitor HVAC equipment to ensure it is operating properly. This might be done with flow switches, current relays or auxiliary contacts on motor starters, for instance.
- Provide time schedule on/off control for lighting. Lighting should be broken into small zones so that control of lights in small areas can be overridden for off-hour occupancy.
- Provide readily accessible means to override HVAC and lighting control for off-hour operation. This might be through bypass timers, push buttons on HVAC thermostats, dial-in telephone interfaces, etc.
- Provide optimum start/stop for HVAC systems. Optimum–start control logic adjusts the normal system start times each morning as a function of actual space temperatures and outdoor air temperature. This allows the system to start as late as possible just to bring the building to comfort levels at the normal hour of occupancy. Optimum–stop control logic adjusts normal system off times so that equipment may be shut off early while building thermal mass keeps space temperatures within the comfort zone.

HVAC System Prescriptive Requirements

System Sizing

Most HVAC system components are less efficient at part load than they are at full load. Section 9.4(a) of the Code therefore requires that HVAC systems and equipment be sized to provide no more than the cooling and heating design loads calculated in accordance with Section 9.3(a).

The intent of this restriction is often misunderstood because the term "oversizing" is commonly used in two different ways. As it applies here, "oversizing" is selecting equipment that has a higher output capability than required by the load. But the term is also used to describe the sizing of equipment using design parameters that are more conservative than is typical for the industry, such as sizing a duct for 0.05 in./100' pressure drop, using a 49 in. fan when a 44 in. fan would work, sizing a coil or filter bank for 300 fpm, or selecting a cooling tower to deliver 75°F condenser water. These designs are not intended to increase the capacity of the system and are not considered "oversizing" in the context of Code. In fact they will result in improved energy efficiency and should be encouraged. On the other hand, sizing a chiller for 200 tons when the load is 150 tons, or sizing a fan for 10,000 cfm when the load requires only 8,000 cfm, is considered oversizing. This type of oversizing will almost always result in reduced energy efficiency. The important distinction between the two is that "oversizing" in this context results in a system whose design capacity exceeds the required load.

Exceptions:

There are five exceptions to system sizing requirement.

a) Equipment capacity may exceed design loads provided the equipment is the smallest size that can meet the load within the available options of the desired equipment line. The "desired equipment line" is at the discretion of the designer. (See Example 4-U as follows.)

b) Equipment capacity may exceed design loads if it can be shown that oversizing will not increase building energy costs. Calculations used to justify the use of this exception must include both full and part load performance; The designer should perform an analysis consistent in accuracy with the method prescribed in Article 13. (Note: with the definition of "oversizing" described above, it is very unlikely that this exception will be applicable to any typical HVAC equipment.)

c) Equipment capacity may exceed design loads if the equipment is intended for stand-by use only, and controls are provided that allow its operation only when the primary equipment is not in operation.

d) Multiple pieces of the same equipment type, such as multiple chillers or boilers, may have a total capacity exceeding the design load if controls are provided to sequence or otherwise optimally control the equipment as a function of operating load. This is an ideal design technique to allow for additional load for future expansion without reducing energy efficiency. For instance, if there is a perceived need for future additional chiller plant capacity, rather than installing one oversized chiller and associated pumps, which would not be allowed by the Code, multiple pumps and chillers with a total capacity exceeding the current design load, staged as required by the load, could be installed. This design also provides redundancy to mitigate the impact of equipment failure.

Example 4-U Selection of Equipment Within a Manufacturer's Line

Q

A designer wishes to install a certain brand of equipment because of price, support by a local vendor, and availability. But a competing manufacturer has equipment that more closely matches the required loads. Does the latter equipment have to be used to minimize oversizing?

A

No. Exception (a) allows the designer to select the equipment that best meets the load "within available options of the desired equipment line." This may seem to be an overly generous exception, but it would be impractical for a designer to search all available equipment manufacturers to find the one that best meets the design loads. A building with multiple air conditioners might each end up being manufactured by different companies, which is obviously impractical, not to mention a long term maintenance nightmare.

Example 4-V Chiller Oversizing

Q

A centrifugal chiller part load performance curve shows that it has higher efficiencies between 50% and 100% load than it does at full load. Does a chiller oversized to take advantage of this fact comply by exception (b).

A

Not likely. First, oversizing the chiller would also require oversizing the chilled and condenser water pumps which will almost certainly not have better performance at part loads since they are generally constant volume. The oversizing restriction applies to pumps as well as primary equipment such as chillers and boilers. Second, one has to be careful when analyzing chiller part load performance curves. They often include the effects of "condenser relief" which is an assumed reduction in condenser water temperatures at reduced load. Without this relief, most chillers will only have better part load efficiencies down to 80% to 90% load or so. At lower loads, efficiency will be worse than full load, and when pump energy is taken into account, overall chiller plant performance for the entire year will almost certainly be worse than for a properly sized chiller. In addition, if the chiller experiences very low loads, it will either cycle excessively, which increases equipment wear, or, if it is fitted with hot gas bypass to provide stable low load operation, it will use excessive energy.

e) For a single piece of equipment that has both heating and cooling capability, only one function, either the heating or the cooling, need meet the oversizing restriction. Capacity for the other function must be the smallest size, within available equipment options, that meets the load requirement. This exception is primarily intended to apply to unitary equipment, such as heat pumps or gas/electric units. These units are generally selected to meet the space cooling load, which often leaves them oversized for heating because of the nature of the equipment (such as heat pumps whose capacity in the heating mode will be determined by its capacity in the cooling mode since the same compressor and heat exchangers are used) or by limited heating options (such as gas-electric units for which there are typically only one or two gas furnace options, the smallest of which may be larger than needed.)

Simultaneous Heating and Cooling

As air conditioning system designs were developed in the late '50s and early '60s, energy costs were a minor concern. The systems were designed primarily to provide precise temperature control with only secondary consideration of energy costs. Zone temperature control was achieved by reheating cold supply air (constant volume reheat system), recooling warm supply air (such as perimeter induction systems), or mixing hot and cold air (constant volume dual duct and multizone system). While these systems provided fine temperature control, they did so at great expense of energy.

To reduce this type of energy waste, Section 9.4(b) of the Code requires that zone thermostatic and humidistatic controls must be capable of sequencing the supply of heating and cooling to each space. These controls must prevent:

- Reheating
- Recooling
- Mixing or simultaneous supply of air that has been previously mechanically heated and air that has been previously cooled, either mechanically or by economizer systems
- Other simultaneous operation of heating and cooling systems to the same zone

Single zone systems, provided their controls are capable of sequencing typical heating and cooling, will inherently meet these requirements. Some multiple zone systems require the use of simultaneous heating and cooling for zone temperature control. In usual Hawaii multizone systems, uncooled and cooled air are mixed and there is no heating.

Exceptions

There are five exceptions to the simultaneous heating and cooling requirements.

a) Simultaneous heating and cooling is allowed if it is minimized by use of variable air volume (VAV) controls. These controls must reduce the air flow to each zone that is being reheated, recooled, or mixed to a minimum rate that does not exceed the larger of the following:

- 30% of the zone peak supply air volume. This criterion recognizes that typical air outlet performance drops off at low flows, reducing its ability to effectively mix supply air with room air.
- The minimum required to meet ventilation requirements. See the discussion under *Ventilation* above regarding the different philosophies for setting VAV box minimum volume setpoints to maintain ventilation rates.
- 0.4 cfm/ft^2. Many designers feel that a minimum circulation rate of supply air must be maintained for comfort. There is little empirical evidence that minimum circulation must be maintained for comfort, and in fact ASHRAE Standard 55 states that there is no minimum air velocity required for comfort. Nevertheless, with little or no air movement, occupants have been known to complain of "stuffiness."

b) Zones where special pressurization relationships or cross-contamination requirements are such that VAV systems are not practical. This exception might apply to some areas of hospitals, such as operating rooms, and to laboratories which must be maintained at positive (or negative) pressures to prevent contaminants from entering (or escaping). VAV systems have been successfully used in these applications in an effort to reduce energy costs, but control is very complicated and requires precise air flow measuring and/or pressure measuring instruments. The risk of a failure of these controls, such as the possible release of dangerous chemicals or bacteria, may not be worth the potential energy savings.

c) Systems where at least 75% of the energy for reheating or producing warm air supply in mixing systems is supplied by heat recovered from some process or equipment within the building (such as chiller condenser heat), or from a solar heating system installed at the site.

d) Zones where precise humidity levels must be maintained, such as some areas of museums where sensitive materials are displayed or stored, or some computer rooms where equipment must be maintained within precise humidity ranges. Note that much of the computer equipment manufactured today does not require this precise humidity control, such as common personal computers and most mini-computers. Also note that Article 9.3(b)(1) of the Code requires that systems serving these types of spaces be separate from those serving zones that only require comfort conditioning.

e) Zones with a peak supply air quantity of 300 cfm or less. This exception allows reheat to be used for small subzones of a larger zone. For instance, an air-conditioner might serve an office space, but more heat is needed at the front entry area to offset infiltration when doors are opened. If the supply to the entry is less than 300 cfm, then a reheat coil may be installed to meet this special heating requirement.

Fan System Design Criteria

Fans are often the largest energy-using components of HVAC systems. However, regulating fan system design to improve performance is made difficult by the wide number of fan applications, from small fan-coils serving a single zone to large central fan systems serving entire buildings.

Some buildings are composed of many small fan systems that together consume a large amount of energy. But they are not regulated by the Code for a few reasons: First, it is simply impractical to require the designer to demonstrate compliance for a myriad of different fan systems in a building. More importantly, it is unlikely that regulations would have a significant impact on the energy used by such small systems. Most small air conditioners and fan-coils are very limited in the external pressure they can overcome anyway, so it is unlikely that designers are wasting significant amounts of fan energy by poorly designing air distribution systems. Last, it would be difficult to establish fan power limits that are applicable to all fan applications; in one case the limit may be overly stringent while in another the limit is easily met and compliance demonstration becomes just a time wasteful exercise.

The fan power limits in Section 9.4(c) of the Code are therefore upper limits that will really have a limiting impact only on relatively large systems, systems that have significant fan system pressure drops:

Example 4-W Zone Dehumidification Controls - Open Freezer Cases

Q

An air conditioner serving a grocery store with open freezer cases includes dehumidification controls to reduce frosting on the cases. The controls cause the supply air to be overcooled to remove moisture then reheated to satisfy space thermal requirements. Does this system comply with Section 9.4(b)?

A

Yes, it meets exception (D). But there may be other restrictions in the Code: Section 9.3(b)(1) may require that other areas of the grocery store that do not require humidity control, such as storerooms and adjacent offices, be served by separate systems.

- Fans that supply a constant volume of air whenever the fan is operating must have a total fan system power demand no higher than 0.8 watts per cfm of supply air (Section 9.4(c)(2)).
- Fan systems whose supply volume varies as a function of load (VAV systems) must have a total fan system power demand no higher than 1.25 watts per cfm of supply air (Section 9.4(c)(3)(A)).

These fan power restrictions are based on the total fan system power demand, which is defined as the energy demand of all fans in a system which operate at design conditions to supply air from the heating or cooling source (such as coils) to the conditioned spaces and return it back to the source or exhaust it to the outdoors. The following guidelines should be used to determine fan system power:

- One fan system is separate from another if they have different heating or cooling sources. For instance, if a large ballroom is supplied by two air handlers each with separate supply fans and heating and cooling coils, they are considered two separate systems even though they both serve the same room.
- Fans that ventilate only, such as garage exhaust fans or equipment room ventilation fans that transfer only unconditioned outside air, do not qualify as a fan system in this context. Fan systems must include a heating or cooling source. (In any case, fans that only ventilate are unlikely to have any problems meeting the design requirements of this section since their pressure drops are typically very low.)
- Only fans that operate at "design conditions" need be included. For a heating supply fan system, only fans that operate at design heating conditions are included, and for cooling systems, only fans that operate at design cooling conditions are included. For systems that have both heating and cooling capability, the system would be rated by the higher of the power required at heating design conditions or cooling design conditions.
- Only fans that supply air from the heating or cooling source to the conditioned space, return the air from the space back to the source, or exhaust air from the conditioned space to the outdoors need be included. Fans that simply recirculate air locally (such as conference room exhaust fans) need not be included.
- The fan "supply cfm," the denominator in the fan power ratio, is the air supplied from the cooling or heating source. Air that is inducted into this air stream at the space (such as induction systems) is not included in the "supply cfm."

Exceptions

The fan design criteria of Section 9.4(c) of the Code do not apply to the following:

a) Small fan systems, those with fan motor horsepowers totaling 10 hp or less.

b) Unitary equipment for which fan energy is included in the efficiency ratings of Article 10. This would include all unitary cooling equipment whose cooling performance is measured by EER or SEER, or whose heating system performance is measured in HSPF.

c) For the purpose of demonstrating compliance with this section, the additional fan power required by air treatment or filtering equipment with final pressure drops in excess of 1 in. wg need not be included.

Fan power can be calculated from the following equation:

$$W = 746 \times \left(\frac{BHP}{\eta_m \times \eta_d}\right) \tag{4-E}$$

where

W = the fan power in watts

BHP = the fan brake horsepower, which is the power required at the fan shaft, measured in horsepower

η_m = the fan motor efficiency

η_d = the drive efficiency, such as belt drives and, where applicable, variable speed drives

The fan brake horsepower requirement can be found in manufacturer's catalog data or generated by their proprietary computer programs. Where data are not available, assume that fan brake horsepower is equal to fan motor horsepower.

Motor efficiencies will vary by motor type, speed and size. Table 4-J below provides typical motor efficiencies which should be used if actual data are not known. High efficiency motor data are based on NEMA Energy Efficient motor classification. Standard motor data are from the ASHRAE Fundamentals Handbook, (1993), page 26.10.

Belt drive efficiencies vary depending on the number and type of belts. If better data are not available, assume belt drives are 97% efficient. Variable speed drive efficiencies, which vary with drive type, can be obtained from the manufacturer.

In general, only large central systems, particularly those with long, high pressure duct runs or poor fitting designs and those with return fans and/or series type fan-powered boxes, will find the fan-power ratio requirements of the Code to be limiting. Smaller systems will generally comply without any special efforts on the part of the designer.

Section 9.4(c)(3)(B) of the Code also limits VAV system performance at part load. For individual VAV fans with motors 25 hp or larger, the power demand at 50% flow must not exceed 50% of the full load power requirement, based on manufacturer's test data.

Figure 4-G shows generic part load performance curves for several fan types and static pressure control systems. It is based on typical fan selections with static pressure setpoints equal to 1/3 of the total system static pressure. Actual fan performance will depend on fan selection, the location of the static pressure sensor and the control setpoint.

The curves indicate that only air-foil (AF) and backward-inclined (BI) centrifugal fans might have a problem meeting the 50% power at 50% cfm requirement. These fans, if over 25 hp, will have to be fitted with variable speed drives to meet the Code, or another fan type such as a vane-axial fan with variable pitch blades will have to be used.

Example 4-X Calculation of Fan Energy - Fan Coil System

Q

A building HVAC system consists of 40 fan-coils serving individual zones, each with 1/3 hp motors. Does this system need to comply with Section 9.4(c)?

A

No. Each fan-coil is a separate fan system because each has a separate cooling and heating source. The total fan system power for each fan system is only 1/3 hp, so exception (i) applies to each and the systems are exempt from meeting the requirements of this section.

Example 4-Y Adjustment of Fan Energy - Excess Filter Pressure Drop

Q

A supply fan is rated at 4 in. wg total static pressure including a filter assembly with a final (change-out) pressure drop of 1.25 in. How is the supply fan energy calculated for compliance purposes?

A

The supply fan energy need not include the energy required by the filter assembly above 1 in. wg. So the fan power would be based on a total rating static pressure of

$$SP = \text{design } SP - (\text{filter } SP - 1 \text{ in.}) = 4 \text{ in.} - (1.25 \text{ in.} - 1 \text{ in.}) = 3.75 \text{ in.}$$

Fan energy would be determined from the supply fan curves or rating tables at the design air flow and 3.75 in. wg static pressure. As an approximation, fan power without the added filter pressure drop may be estimated to be $(3.75/4.0)^2$ or 88% of the fan power at the 4 in. design condition.

Example 4-Z Fan System Design Requirements - VAV Change-Over System

Q

What are the fan system design requirements for a variable air volume change-over system (also called a variable volume and temperature system) which includes a bypass damper at the fan.

A

This system is variable volume at the zone level, but the bypass damper will maintain a relatively constant air flow through the fan. The system is therefore a constant volume system in this context, and it must meet the 0.8 w/cfm power ratio requirement.

Example 4-AA Fan Power Calculation – VAV System

Q

Is the central VAV system described below in compliance with Section 9.4(c)?

Quantity	Fan Service	Design CFM, each	Brake Horsepower	Motor Horsepower
2	Supply fans with variable speed drives	75000	70.5	75 high efficiency
1	Toilet exhaust	6750	2.7	3 high efficiency
1	Elevator machine room exhaust fan	5000	unknown	3/4
2	Cooling tower exhaust fans	unknown	unknown	15
15	Conference room exhaust fans	500	240 watts	--
120	Series type fan-powered mixing boxes	1300 (average)	unknown	1/3

A

First, determine which fans to include in the fan wattage calculation. The supply fans are clearly included. (Had return fans been used, they would have to be included in the calculation.)

The toilet exhaust fan is included since it exhausts conditioned air from the building rather than having it returned to the supply fan and it operates at peak cooling conditions. But the elevator exhaust fan is not part of the system since, it is assumed in this case, that the make-up air to the elevator room is from the outdoors rather than from the building. Had make-up air been transferred from the conditioned space, the fan would have been included.

The cooling tower fans operate at design conditions but they also are not part of the system because they circulate only outside air.

The conference room exhaust fans are assumed to be transfer fans; they simply exhaust air from the room and discharge it to the ceiling plenum. Since this air is not exhausted to the outdoors, the fans are not included.

The series type fan-powered VAV boxes are included since they assist in supplying air to the conditioned space and operate at design cooling conditions. If the boxes were the parallel type, they would not be included since they would not operate at design cooling conditions.

The fans that are included and their power requirements are:

Fan Service	Quantity	Wattage Calculation	Power each, watts	Total Power, watts
Supply fans	2	746 * 70.5 /0.94 /0.97 /0.95	60,716	121,432
Toilet exhaust fan	1	746 * 2.7 /0.86 /0.97	2115	2115
Fan powered VAV boxes	120	746 * 1/3 /0.56	444	53,280
Total				176,827

In these calculations, motor efficiencies were taken from Table 4-J above. The supply and toilet exhaust fan drive efficiencies were assumed to be 97% (belt drives). The fan-powered boxes are direct drive so they have no drive losses. Since the actual brake horsepower of these fans was not known, it was assumed to be equal to the motor nameplate rating. The supply fan variable speed drive efficiency was found from the manufacturer to be 95%.

Example 4-Y Fan Power Calculation – VAV System (Continued)

The final fan-power ratio is

$$\text{Ratio} = \frac{\text{total fan watts}}{\text{total supply cfm}}$$

The total supply air quantity in this formula is the air flow rate supplied through the cooling source, which is equal to the total of the two supply fan air flow rates in this case. It is not the total of the fan-powered VAV box air flow rates; although this is the ultimate supply air rate to the conditioned space, this entire air flow does not flow through the cooling source. Therefore,

$$\text{Ratio} = \frac{176{,}827}{150000} = 1.18 \text{ W / cfm} \leq 1.25 \text{ W / cfm}$$

The series fan-powered VAV boxes supply a constant flow of air to the conditioned space, but the primary air flow, the air flow through the cooling source, varies as a function of load, so this system meets the definition of a VAV system which is limited to 1.25 w/cfm. Therefore the system complies .

Example 4-BB Calculation of Fan Power Energy – Floor-by-Floor System

Q

A high-rise building has floor-by-floor supply fan systems but central toilet exhaust fans and minimum ventilation supply fans. How is the Code applied to this system?

A

Each air handler counts as a fan system. The energy of the central toilet exhaust and ventilation fans must be allocated to each air handler on a cfm weighted basis. For instance, if one floor receives 2,000 cfm of outside air and the outside air fan supplies a total of 10,000 cfm at 3.5 kW, 20% (2,000/10,000) of the fan energy or 700 watts is added to the fan power for the floor's fan system.

While only an effective requirement for large AF and BI centrifugal fans, variable speed drives are likely to be cost effective for VAV systems with almost any fan type, except perhaps vane-axial fans for which variable pitch control provides excellent part load performance, down to 10 hp or 15 hp. Variable speed drives will also reduce noise levels at part load, compared to inlet vanes and discharge dampers which increase noise at part loads, and they will allow even air-foil fans to be operated down to very low flow rates (see discussion above under Off-hour Isolation).

Table 4-J Typical Motor Efficiencies (%)[a]
(from ASHRAE Standard 90.1- 1989 User's Manual)

Nameplate Rating (hp)	Standard Motor	High Efficiency Motor
1/20	35	--
1/10	35	--
1/8	35	--
1/6	35	--
1/4	54	--
1/3	56	--
1/2	60	--
3/4	72	--
1	75	82.5
1-1/2	77	84.0
2	79	84.0
3	81	86.5
5	82	87.5
7-1/2	84	88.5
10	85	89.5
15	86	91.0
20	87	91.0
25	88	91.7
30	89	92.4
40	89	93.0
50	89	93.0
60	89	93.6
75	90	94.1
100	90	94.1
125	90	94.5
150 and up	91	95.0

[a] Open Motors, 1800 RPM synchronous speeds, nominal efficiencies, from NEMA Standard MG 12.55, dated 1-11-89. See Table 5-1 of the Code for high efficiency ratings or other motors.

Pumping System Design Criteria

The requirements of Section 9.4(d) of the Code apply to pumping systems with total system pump motor horsepowers larger than 10 hp. Pumping system total power is defined as the energy required at design conditions to supply fluid from the heating or cooling source (such as chiller or boiler) out to heat exchangers or coils and return it back to the source.

Piping Pressure Drop Requirement

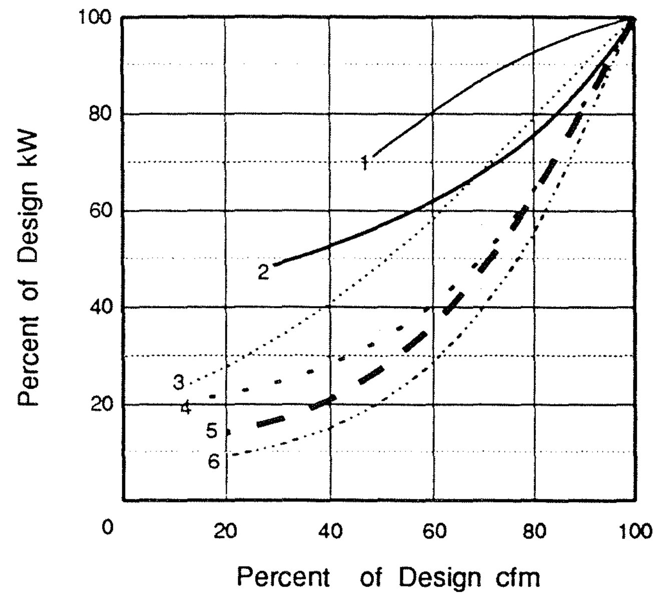
The Code recommends piping systems be designed for a friction pressure loss rate no greater than 4.0 ft of water per 100 equivalent ft of pipe.

The 4 ft per 100 ft friction rate was selected based on typical piping sizes, costs and operating hours. The actual life-cycle cost optimum pipe size, the size that balances first costs with pump energy costs, will vary by location (labor rates, material availability), design (number of fittings and specialties), and the number of system operating hours. Smaller pipe sizes will generally be optimized at higher friction rates while larger pipe sizes are optimized at lower friction rates. Systems that operate many hours, such as a system that requires 24-hour operation, or a condenser water system serving a hydronic heat pump system or water economizer system which will operate whenever the building is occupied, should be sized more conservatively than a system that operates fewer hours.

Variable Flow Requirement

The Code requires that pumping systems with modulating or two-position controls must be designed for variable flow, employing either variable speed driven pumps or staged multiple pumps. The system must be able to operate down to 50% of design flow or lower. Basically this means that two-way control valves rather than three-way control valves must be used.

Figure 4-G Part Load Curves for a Variety of Fans
(from ASHRAE Standard 90.1- 1989 User's Manual)



① Airfoil or backward-inclined centrifugal fan with discharge dampers

② Airfoil centrifugal fan with inlet vanes

③ Forward-curved centrifugal fan with discharge dampers or riding curve

④ Forward-curved centrifugal fan with inlet vanes

⑤ Vaneaxial fan with variable pitch blades

⑥ Any fan with variable speed drive (mechanical drives will be slightly less efficient)

Example 4-CC Part Load VAV Fan System Efficiency

Q

A VAV fan system includes a 60 hp supply fan and a 15 hp return fan. Does it have to meet the 50% kW at 50% cfm requirement?

A

Yes. The 60 hp fan must meet the part-load efficiency requirement. However, the return fan is exempt because it is smaller than 25 hp.

Exceptions

The following exceptions apply:

a) Dedicated equipment pumps separated from modulating control valves in a primary/secondary loop arrangement are exempt from this requirement. The secondary pump, however, must still meet the variable flow requirement.

b) Systems with only one control valve.

c) Systems that include supply temperature reset controls in accordance with Section 9.4(e)(2) without exception. The reset controls will cause water flow rates through control valves to stay high even at low loads: as water temperatures are raised, coil heat transfer effectiveness is reduced. It is possible to use both variable flow and supply temperature reset, although the energy savings together will not be as high as the savings of each feature individually.

d) Where overall building energy costs from an alternative design can be shown to be lower than for a variable flow system. It is possible that some heat transfer systems will perform better at higher, constant flow rates, offsetting pump energy savings. An analysis consistent in accuracy with the method prescribed in Article 13 should be performed to demonstrate this.

Two-way control valves are less expensive than 3-way valves and because no special pump controls are required, meeting the requirements of this section can reduce system first costs over constant flow systems. Properly designed variable flow systems can also be almost self balancing as well, reducing balancing costs.

Supply Air Temperature Reset

Section 9.4(e)(1) of the Code requires that systems which supply heated or cooled air to more than one zone have controls that reset the supply air temperature at low loads: upwards for cooling systems and downwards for heating systems. Reset offers energy savings in several ways: losses due to zone level simultaneous heating and cooling are reduced; duct losses are reduced; and cooling system efficiency is improved by raising suction temperatures. This occurs directly with DX systems and indirectly, through chilled water reset, with chilled water systems. Reset also provides the secondary benefits of improved low load control at VAV boxes and increased overall circulation rates which can improve indoor air quality.

The reset can be based on any of the following strategies:

- Actual zone requirements, the zone that requires the coldest (cooling systems) or warmest (heating systems) supply air temperature. In other words, supply air temperature setpoint is reset so that the zone whose supply air flow is closest to its design maximum is maintained near its maximum flow. With proportional controls, this is the zone with the highest (or lowest) thermostat signal. This strategy is theoretically the most energy efficient and most reliable at maintaining comfort. Reset can also be based on zone temperature: supply air setpoint is reset so that the "warmest" or "coolest" zone is maintained at a given high or low temperature limit. But since zones may not all have the same setpoints, this strategy will not ensure comfort and should be discouraged. Reset by zone demand is practical when zones have direct digital controls that can communicate with the fan system controls. But where zones are pneumatically or electronically controlled, the strategy seldom works well in practice due to poor zone thermostat calibration or poor signal selection and transmission.
- Peak or representative zone requirements. If supply air setpoints are limited within a fixed range (such as from 55°F to 60°F), this strategy can work well. The zones selected must be the zones that will usually require the lowest

supply air temperatures for cooling systems, such as south and west facing zones. A possible flaw with this strategy is that the zone that may actually require the most cooling is not one of those monitored.

- Load indicators such as return air temperature or fan static pressure control signal. These strategies should be used with caution, however, since they provide only an indication of average zone requirements. Some zones may be under cooled when the average zone is satisfied, or some zones may have lower or higher setpoints than the average.
- Outside air temperature. This strategy works best for heating systems since heating loads in the most demanding zone will be almost proportional to the difference between outside and inside temperatures.

If used, the supply temperature must be reset by at least 25% of the design supply air to room air temperature difference. For instance a cooling system with a design supply air temperature of 55°F and a design space air temperature of 75°F must reset supply air temperature by up to 5°F (25% of the difference between 75°F and 55°F) or from 55°F up to 60°F.

Zones with relatively constant loads, such as interior zones, must be designed for the fully reset supply temperature. For a system with supply air temperatures reset from 55°F to 60°F, interior zone air outlets and terminal devices would have to be sized for 60°F supply air temperature, increasing their size above that required for 55°F design temperature. If this were not done, no reset would be possible without causing discomfort in interior spaces that have constant loads. (Fan systems and central distribution ductwork would still be sized at the 55°F design condition.)

Exceptions

The following exceptions apply:

a) Reset is not required for systems that comply with Section 9.4(b) of the Code without using exceptions (A) or (B). In other words, reset is not required for systems that either require no simultaneous heating or cooling for zone temperature control, or those that do but fall under exceptions (C), (D), or (E) of Section 9.4(b). The reason for this exception is that systems that meet Section 9.4(b) will have no zone level reheat losses, so reset will offer little energy savings. Examples include VAV systems with fan-powered boxes or dual-duct VAV systems. Note that ventilation codes may not be met with zero minimum volumes. See the discussion under *Ventilation* above.

b) Reset is not required where it can be shown that energy costs are increased over constant supply temperature systems. While supply temperature reset reduces reheat energy and can improve chiller and economizer performance, it also will increase fan energy. For fan systems that are very efficient at part load, such as those with variable speed drives, and that have very low minimum air flow rates at the zone level so reheat is minimized, it is possible that reset will increase overall energy usage. An analysis consistent in accuracy with the method prescribed in Article 13 should be performed to demonstrate this. Note that reset may still be desirable even if it increases energy costs because it also increases circulation rates which may improve indoor air quality.

Supply Water Temperature Reset

Resetting primary chilled water temperatures upward at part load improves the efficiency of the primary equipment and reduces energy losses through piping. In Section 9.4(e)(2), the Code requires that all chilled water systems include controls that reset supply water temperatures upward at low loads.

Reset may be based on any of the following:

- Actual system demand, the cooling or heating coil that requires the coldest (cooling systems) or warmest (heating systems) water. In other words, supply water temperature is reset so that the coil control valve that is the furthest open is maintained near wide open. This strategy is both the most energy efficient and the most reliable at ensuring no coil is "starved." However, it is only practical if there are very few coils served by the system or if all coils are controlled by a direct digital control system that can communicate with the chiller or boiler control systems.
- Building load indicators such as return water temperature. This signal should be used with caution, however, since it provides only an indication of average system requirements. For instance, if one coil is at near design conditions while all others are at low load, this strategy would "starve" the first coil and comfort levels in the space it served would not be maintained. This strategy also does not work well if coils are used for dehumidification since colder supply water may be required even at low loads.
- Outside air temperature. This strategy works well for heating systems since space loads are almost proportional to the difference between inside and outside temperatures. This strategy will usually not be reliable for cooling systems because the majority of space cooling loads are independent of outside air temperature.

Supply temperature must be reset by at least 25% of the design supply to return water temperature difference. For instance, a chilled water system designed for 44°F supply water and 56°F return water at design conditions would have to reset temperatures by 3°F (25% of the difference between 56°F and 44°F) or from 44°F up to 47°F.

The following exceptions apply:

a) Systems that are designed for variable flow in accordance with Section 9.4(d)(3). For such systems, the use of supply water temperature reset will reduce the pumping energy saved by the variable flow design. This exception, together with exception (iii) to Section 9.4(d)(3), means that hydronic cooling systems either have to be variable flow or have supply temperature reset controls, but not both.

b) Where it can be shown that supply temperature reset will increase building energy costs. Unlike supply air temperature reset which can significantly increase fan energy costs, supply water temperature reset will usually only have a small effect on flow rates. This is because reset affects the water temperature rise (to which flow rate is inversely proportional) indirectly only by reducing coil heat transfer effectiveness. It is therefore unlikely that reset will cause a pump energy increase large enough to offset the reduced piping losses and increased primary equipment efficiency. An analysis consistent in accuracy with the method prescribed in Article 13 should be performed to justify the use of this exception.

c) Systems for which supply temperature reset will cause improper operation of heating, cooling, humidification or dehumidification systems. This exception applies to systems for which supply water temperature cannot be reset by 25% or more of the design supply to return water temperature difference

Example 4-DD Reset Requirements – Return Water Chiller Controls

Q

Cylinder unloading for a reciprocating chiller is controlled by return chilled water temperature rather than supply water temperature for more stable operation. How is the reset control requirement applied to this application?

A

No other controls are required. By maintaining a constant return water temperature, supply water temperature is indirectly reset as required.

at any time without causing improper or inadequate temperature or humidity control. Examples include systems requiring dehumidification capability at all times of the year. This is true of very many if not most systems in Hawaii. This exception should not be used for systems for which reset by actual coil demand (strategy 1 described above) is practical, such as systems with direct-digital control of all valves, since this reset strategy will not allow any coil to be "starved."

d) Systems with less than 600,000 Btu/h design capacity. For such small systems, the cost of reset controls, which are relatively independent of system size, may not be cost effective.

5. Water Heating

General Information

Overview of the Chapter

This chapter covers the requirements of service water heating equipment and systems. This includes the production and distribution of hot water for:

- Residential buildings and hotels
- Restrooms
- Showers
- Laundries
- Kitchens
- Pools and spas
- Commercial enterprises such as car washing and beauty salons

These requirements apply to new water heating systems and equipment which are installed in new buildings, major additions to buildings or portions of buildings undergoing major alteration. They do not apply to emergency replacements of existing water heaters. They also do not apply to process water heating systems such as those used for manufacturing or food processing.

A short overview of the residential requirements is provided in Appendix A. It describes all the requirements for a water heating system which serves a single residential unit.

Table 5-A summarizes the general water heating requirements. These basic requirements must be satisfied for all water heating systems. The energy recovery requirement is part of Article 9 of the code, HVAC systems, and is discussed in Chapter 4.

Example 5-A Emergency Water Heater Replacement

Q

An aging water heater in a laundromat is replaced to avoid increasing maintenance costs. No other improvements to the facility are planned. Does the code apply?

A

No. since the replacement is not part of a major renovation or part of a new water heating system, the code does not apply.

Example 5-B Residential Addition

Q

A homeowner adds a second story, including two bedrooms and a bathroom. She installs a 30 gallon electric water heater to serve the new bathroom. How does the code apply?

A

As a new water heating system installed in an addition, it must meet the code. The heater must meet minimum efficiency and temperature control requirements. In addition, the outlet pipe must be insulated and low-flow showers and faucets are required.

Table 5-A Summary of Water Heating Requirements

		Page
Basic Requirements	Apply to all water heating systems.	
Sizing of Systems 11.3(a)	Applies to all systems. Requirements for properly sizing a water heating system.	5-4
Equipment Efficiency 11.3(b)	Applies to all water heating equipment. Residential size water heaters must meet these requirements in order to be sold in the U.S.. Larger equipment must meet minimum thermal efficiency and standby loss requirements.	5-4
Piping Insulation 11.3(c)	Applies to all systems. For circulating systems, insulation required on hot water pipes. For non-circulating systems, insulation required on pipe near the storage tank.	5-12
Temperature Controls 11.3(d)	Applies to all systems. Controls allow water temperature to be set down to 90°F for commercial systems and 110°F for residential systems.	5-8
Multi-Temperature Systems 11.3(e)	Applies to systems where temperatures higher than 130°F are required at certain outlets for a particular use (such as commercial dish washing). Requires use of booster heaters.	5-9
Time Controls 11.3(f)	Applies to circulating systems and systems designed to maintain temperatures in hot water pipes. Automatic controls to turn off system when hot water not required.	5-12
Hot Water Conservation 11.3(g),(h)&(i)	Applies to all systems. Flow control faucets and shower heads. Different requirements for public and private lavatory faucets.	5-14
Swimming Pools, Hot tubs and Spas 11.3(j)	Applies to all permanent swimming pools, hot tubs and spas. Solar or heat pump heating and time controls on pump systems.	5-16
Energy Recovery 9.3(h)	Condenser heat recovery air conditioning systems larger than 10 tons or compressors larger than 15 hp with coincident water heating loads.	Chapter 4

A glossary explaining technical terms used in this section is found at the end of the chapter.

When to Use the Energy Cost Budget Method of Compliance

The energy cost budget method involves computer simulations of building energy use. Use of this method requires computer modeling skills and will generally be used only on large building projects.

The energy cost budget method of compliance allows trade-offs between different building systems. Although the water heating system must still meet all the basic requirements, by using the energy cost budget method, a designer may be able to offset energy usage in the envelope, lighting or HVAC systems through increased efficiency in the service water-heating system. The base case service water-heating system for comparison in the ECB method will be that which meets the minimum requirements of this chapter and which uses the same fuel type as the proposed water heater.

General Information on Design of Service Hot-Water Systems

For some building types, service water heating can be a major energy consumer. In residences and hotels, for example, water heating may account for up to 25% to 40% of the total energy usage. Fortunately, this component of energy usage is easy to control through application of some basic, cost-effective, design practices: *hot water waste* is reduced through use of flow limiting or metering terminal devices; *standby losses* are limited through application of thermal insulation; *distribution losses* can be reduced through thermal insulation and circulation-pump controls or eliminated through point-of-use heaters; and, *waste heat* or *solar energy* can be harnessed to increase overall system efficiency. (See *solar water heating* and *heat recovery* in the glossary at the end of this chapter).

The requirements of this chapter are for service water-heating equipment and systems only. However, the principles presented could apply to energy efficient process water-heating systems and equipment as well.

Although compliance with the code assures a minimum level of water heating system performance, the designer is encouraged to investigate designs that exceed these requirements. Application of heat recovery, solar energy or high efficiency equipment can create a system that is more efficient than the code requires *and* exhibit an excellent return on investment. Reductions in water flow or temperature below the requirements of Article 11 will usually be cost-effective investments in conservation. These include: specifying low-flow shower heads which exceed the requirements of this section; extending the public restroom flow requirements to all restrooms; specifying low-water usage or low-temperature appliances including, residential and commercial clothes washers and dishwashers; and, recovering heat from gray water.

Basic Requirements

All water heating systems must meet the following basic requirements.

System Sizing

The code prescribes that service water-heating system design loads shall be calculated following the procedures described in Chapter 44 of the ASHRAE HVAC Applications Handbook (1991). The designer may also use procedures developed by equipment manufacturers.

The handbook presents a number of calculation methods. The appropriate approach depends both on the application (such as residential, food service, commercial laundry, etc.) and the type of system (storage heater or instantaneous).

In addition to load calculations, Chapter 44 of the ASHRAE HVAC Applications Handbook (1991) also provides useful information on other aspects of service water-heating systems. These include: the sizing of distribution piping; special considerations in piping for commercial kitchens; problems of water quality and protection from corrosion and scale; design of dual temperature systems; health and sanitation concerns; and numerous references providing water usage and utilization temperatures for a range of building and system types. The values in Table 5-B do not include system heat loss, which must be added to the values from the table.

Table 5-B Commercial Hot Water Consumption Estimates

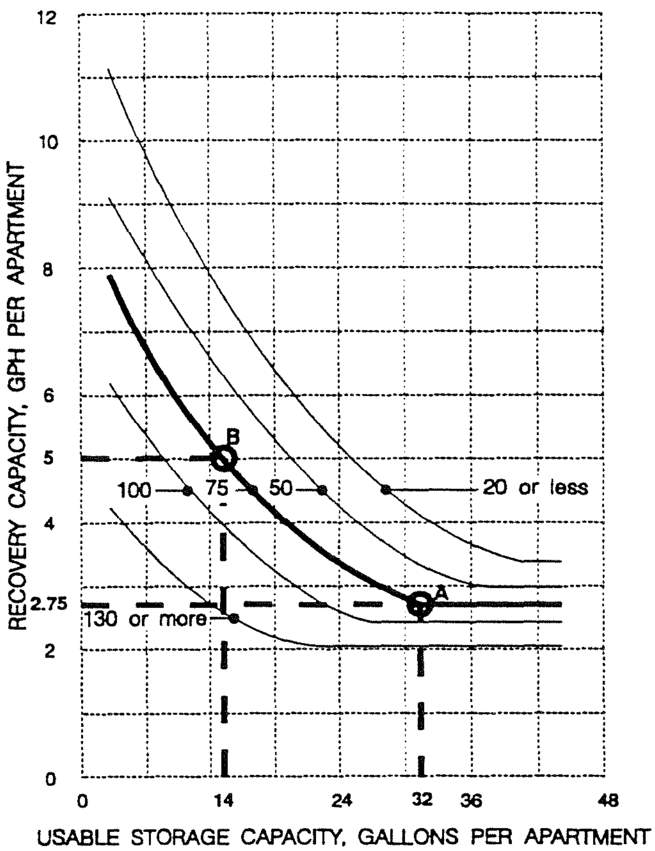
Type of Building	Maximum Hour	Maximum Day	Average Day
Men's dormitories	3.8 gal/student	22.0 gal/student	13.1 gal/student
Women's dormitories	5.0 gal/student	26.5 gal/student	12.3 gal/student
Motels: Number of Units[a]			
20 or less	6.0 gal/unit	35.0 gal/unit	20.0 gal/unit
60	5.0 gal/unit	25.0 gal/unit	14.0 gal/unit
100 or more	4.0 gal/unit	15.0 gal/unit	10.0 gal/unit
Nursing Homes	4.5 gal/bed	30.0 gal/bed	18.4 gas/bed
Office Buildings	0.4 gal/person	2.0 gal/person	1.0 gal/person
Food service establishments:			
Type A - full meal restaurants and cafeterias	1.5 gal/max meals/h	11.0 gal/max meals/day	2.4 gal/max meals/day[b]
Type B - drive-ins, grilles, luncheonettes, sandwich and snack shops	0.7 gal/max meals/h	6.0 gal/max meals/day	0.7 gal/max meals/day[b]
Apartment Houses: Number of Apartments			
20 or fewer	12.0 gal/apt	80.0 gal/apt	42.0 gal/apt
50	10.0 gal/apt	73.0 gal/apt	40.0 gal/apt
75	8.5 gal/apt	66.0 gal/apt	38.0 gal/apt
100	7.0 gal/apt	60.0 gal/apt	37.0 gal/apt
200 or more	5.0 gal/apt	50.0 gal/apt	35.0 gal/apt
Elementary schools	0.6 gal/student	1.5 gal/student	0.6 gal/student[b]
Junior and senior high schools	1.0 gal/student	3.6 gal/student	1.8 gal/student[b]

[a] interpolate for intermediate values

[b] per day of operation

Source: ASHRAE Applications Handbook, 1991, Chapter 44, Table 7.

Example 5-C Sizing Service Water Heater Equipment



Q

What size heater and storage tank would be appropriate for an 80-unit apartment building?

A

From the graph at left (a reproduction of Figure 18 from Chapter 44 of the ASHRAE Applications Handbook (1991)) any heater and storage tank combination that falls on the curve for 75 units would satisfy the load. Selection A is the smallest heater with its corresponding storage size. Selection B represents a larger heater which allows for a smaller storage tank. Either system would satisfy the load; the final decision should be based on economics and available space.

	Selection A		Selection B	
	Per Unit	Total	Per Unit	Total
Recovery Capacity[1] (GPH)	2.75 × 80 =	220.00	5 × 80 =	400.00
Usable Storage (Gallons)	32× 80 =	2,560.00 × 1.43	14× 80 =	1,120.00 × 1.43
Actual Storage[2] (Gallons)		3,200.00		1,600.00

1 This capacity does not account for system heat loss. System heat loss should be added to the loads calculated here.

2 Assuming 70% useful storage capacity.

Equipment Efficiencies

Table 11-1 of the code presents the minimum required efficiencies for water-heating equipment. Equipment is required to have both a minimum heater efficiency (*thermal efficiency* or *C.O.P.*), and a maximum standby loss. Smaller equipment, which falls under NAECA[1], is required to meet a minimum *energy factor* which is a combined measure of thermal efficiency and standby loss. Equipment in the table is classified by use (water heating, pool heating,...), fuel, capacity (*input rating*) and storage size.

The standby loss requirement is waived on storage water heaters and unfired storage tanks that meet all three of the following requirements:

- Over 140 gallons storage capacity
- Tank surface with a thermal insulation of R-12.5 or more
- No standing pilot light.

This exception is provided to overcome the practical difficulties of testing large units by conventional test procedures. It does not relax the requirements of the code, but rather provides an alternative method for compliance. It should be noted that the R-value of the thermal insulation used for this exception is an effective R-value and should account for any short circuits of the insulating jacket.

Equipment data for compliance should be presented on the plans or in the specifications. Data from either manufacturers or nationally recognized rating programs can be used, but must be based on the appropriate test procedure from Table 11-1 in the code.

The designer should note that equipment efficiencies well in excess of those required by the code are readily available. Non-condensing gas-and oil-storage water heaters are available with thermal efficiencies as high as 88%; condensing models are available with recovery efficiencies up to 95%. Standby losses are reported as low as 0.40%/h for storage gas models. Storage electric resistance heaters are available with thermal efficiencies up to 99.9% and standby losses down to 0.06%/h. Air-source heat-pump water heaters have COPs up to 3.8. The designer is encouraged to evaluate the economics of high-efficiency equipment.

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[1] NAECA, National Appliance Energy Conservation Act of 1987. All water heaters sold in the U.S. which fall within NAECA size limits must meet the minimum energy factor requirement.

Example 5-D Equipment Efficiency Requirements Electric Resistance Water Heater

Q

An 82-gallon electric-resistance storage heater with two 7.5 kW elements has the following characteristics: the elements are wired for non-simultaneous operation; a GAMA-certified energy factor rating of 0.87. Does it comply?

A

Since the elements are wired for non-simultaneous operation, the input rating of this model is 7.5 kW and it is subject to the NAECA efficiency requirements. Table 11-1 requires that the energy factor of this unit is greater than or equal to:

$$EF_{min} = 0.93\text{-}(0.00132 \times V) = 0.93\text{-}0.00132 \times 82 \text{ gal} = 0.822$$

This heater complies with the basic requirements.

Example 5-E Equipment Efficiency Requirements Gas-Fired Split System

Q

A split water system consists of a gas-fired heater, circulation pump and storage tank. The heater is rated at 1,825,000 Btu/h input and 1,497,000 Btu/h output. The heater storage capacity is 45 gal, and its standby losses are 4%/h. The storage tank is 400-gal capacity and is insulated to R-16 with sprayed on polyurethane foam. Does it comply?

A

As the storage tank is unfired, over 140-gal capacity and is insulated above R-12.5, it meets the standby loss requirement (this is the exception to 11.4.2). The heater thermal efficiency and input-to-volume ratio are given by:

$$E_t = \frac{Q_{out}}{Q_{in}} = \frac{1497000}{1825000} = 82\%$$

$$\text{Input to Volume Ratio} = \frac{Q_{in}}{V_{heater}} = \frac{1825000 \text{ Btu/h}}{45 \text{ gals}} = 40{,}556 \frac{\text{Btu}}{\text{h-gals}}$$

Table 11-1 sets the following requirements for the heater: the minimum allowable thermal efficiency is 77% and the maximum allowable standby loss is given by:

$$\text{Maximum allowable standby loss} = 2.3 + \frac{67}{V_t} = 2.3 + \frac{67}{45} = 3.79 \frac{\%}{h}$$

The storage tank complies. The heater thermal efficiency complies. The heater needs additional thermal insulation to reduce its standby loss below 3.79%/h to comply. As it is impractical to blanket this unit in the field, the designer should request a model with more insulation from the manufacturer or select another unit that complies.

Example 5-F Equipment Efficiency Requirements Condensing Gas Water Heater

Q

An instantaneous condensing gas water heater has the following characteristics: 1,000,000 Btu/h input; 23 gal storage; 93% thermal efficiency; and, 5.2%/h standby loss. Does it comply?

A

The water heater's input-to-volume ratio is given by:

$$\text{Input to Volume Ratio} = \frac{Q_{in}}{V_{heater}} = \frac{1000000 \text{ Btu/h}}{23 \text{ gals}} = 43478 \frac{\text{Btu}}{\text{h-gals}}$$

Table 5-1 sets the following requirements for the water heater: the required minimum efficiency is 77% and the required maximum standby loss is given by:

$$\text{Maximum standby loss} = 2.3 + \frac{67}{V_t} = 2.3 + \frac{67}{23} = 5.21\%/\text{hr}$$

The water heater complies.

Temperature Controls

Water-heating systems are required to have controls which are adjustable down to a 90°F setpoint. An exception is made for residential units which may adjust to 110°F setpoint. These features should be provided by the manufacturer of the heaters; the designer's responsibility is to specify a complying unit. Both standby and distribution losses will be minimized by designing a system to provide hot water at the minimum temperature required. Table 5-C on the next page summarizes representative hot water design temperatures from the ASHRAE HVAC Applications Handbook (1991).

In addition to the potential energy savings, corrosion and scaling of water heaters and components will be reduced by maintaining the water temperature as low as possible. Another important benefit is the improved safety with respect to scalding. Accidental scalding from temperatures as low as 140°F is responsible for numerous deaths each year.

Designers should be aware that the bacteria that causes Legionnaire's disease has been found in service water heating systems and can colonize in hot water maintained below 115°F. Careful maintenance practices can reduce the risk of contamination. In health-care facilities or service-water systems maintained below 140°F, periodic flushing of the fixtures with high temperature water, or other biological controls may be appropriate. Refer to ASHRAE design guides for further information.

Table 5-C Service Water Temperatures
(from ASHRAE Standard 90.1- 1989 User's Manual)

Use	Temperature (°F)
Lavatory	
Hand washing	105
Shaving	115
Showers & tubs	110
Therapeutic baths	95
Commercial & institutional laundry	180
Residential dish washing and laundry	140
Surgical scrubbing	110
Commercial spray type dish washing as required by N.S.F.	
Rack type	>150 wash 180 to 195 final rinse
Single tank conveyor type	>160 wash 180 to 195 final rinse
Multiple tank conveyor type	>150 wash >160 pumped rinse 180 to 195 final rinse
Chemical sanitizing type (see manufacturer for actual temp required)	140 wash >75 rinse

Source: ASHRAE Handbook 1991 HVAC Applications

Multi-temperature Systems

Where temperatures in excess of 130°F are needed at certain outlets, either booster heaters or separate dedicated remote heaters are required. This requirement saves energy by reducing the standby and distribution losses which are proportional to the water temperature. It also encourages designs which can utilize waste or solar heat for the base load of the service water system.

In a typical hotel, only the kitchen or laundry facilities will require water temperatures in excess of 115°F. As the bulk of the hot water is typically used in the public lavatories and guest rooms, energy would be wasted if the entire water heating system operated at 180°F just to serve the kitchen. A similar situation exists in high-rise residential buildings: typically dish washing is the only end-use requiring water temperatures in excess of 115°F. For these projects, the dishwasher should be provided with a booster heater – a standard option offered by all manufacturers.[1]

A booster heater, Figure 5-A, is a separate unit that draws service hot water from the main water heater and raises the temperature as needed for higher temperature applications. It can be of the storage or instantaneous type. Advantages of this design include the following:

- The high-temperature heater has a relatively small lift in temperature and can therefore be a smaller unit. Often an instantaneous heater can be located in the cabinetry adjacent to the point-of-use, a design which minimizes standby and distribution losses.

[1] The U.S. Department of Energy has required that all new residential dishwashers be supplied with booster heaters effective May 1994.

Figure 5-A Booster Heater for Dual Temperature Service
(from ASHRAE Standard 90.1- 1989 User's Manual)

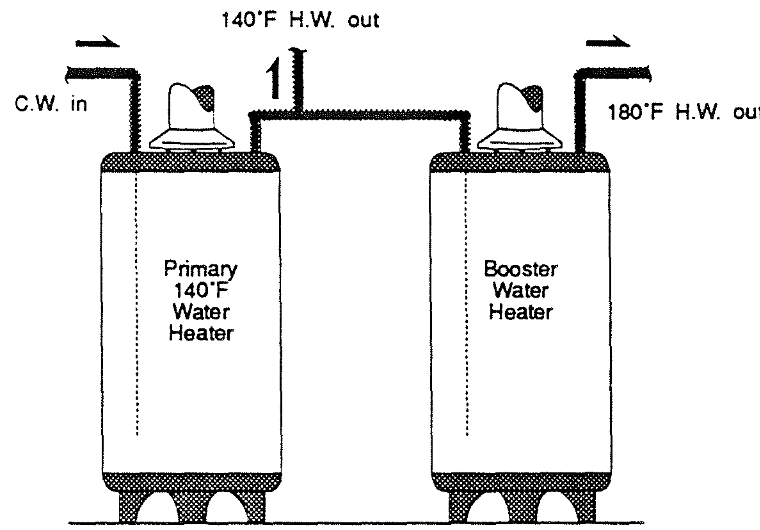
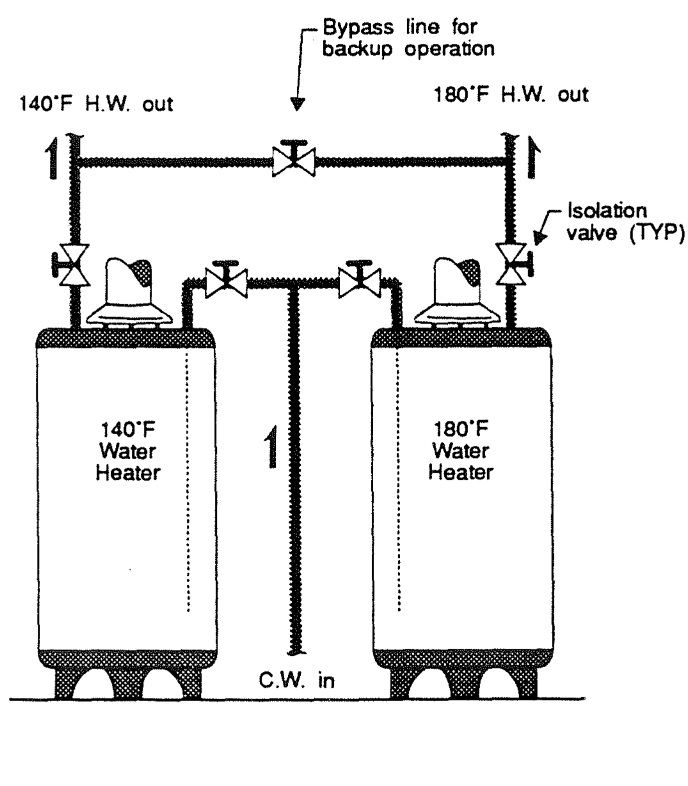


Figure 5-B Dedicated Heater for Dual Temperature Service
(from ASHRAE Standard 90.1- 1989 User's Manual)



• The high temperature system gets the advantage of lower temperature heat recovery or solar heating if it is employed in the main service water heating system.

A dedicated heater, Figure 5-B, lifts the water from the cold water supply temperature to the desired outlet temperature. The primary advantage of this system is that it can provide limited backup for the main service hot-water system. The primary disadvantage is that this design is less adaptable to heat recovery or solar heating.

Exceptions

Exception to the design requirement for dual-temperature systems is provided where the designer can demonstrate that either:

• The energy cost of the system is not reduced by application of the requirement

• The life-cycle cost of a complying system exceeds that of the proposed non-complying system.

When economic calculations are made to seek exception to the requirement, they must include an analysis of both the proposed system, and a complying system of equal capacity. The analysis must consider both the installed and operating costs of the two systems. Installed cost analyses must consider both equipment and labor costs. Yearly operating-cost analyses must consider:

Example 5-G Economic Calculation Dual-Temperature Water-Heating System

Q

A design requires both general service water temperatures of 120°F and 180°F for kitchen equipment. The designer has prepared a cost estimate of two systems: a non-complying single system operating at 180°F with a three-way mixing valve to provide 120°F service water from the 180°F tank; and a complying system operating at 120°F with a separate booster heater for the kitchen. The designer has produced an energy simulation of both systems using ASHRAE and American Society of Plumbing Engineers (ASPE) load profiles. These simulations account for energy losses in the tank, heaters and distribution piping. The data on the two systems are provided in the table below. Will the single system operating at the 180°F temperature comply?

A

Using a 3% discount rate and 15-year life for the equipment, the ESPWF factor is 11.94 (from Table 5-F). The life-cycle cost comparison of the two systems is presented in the table below.

	Single Heater 180°F System		System with Booster Heater	
Costs	Actual	Present Worth	Actual	Present Worth
Installed	$11,800 =	$11,800	$13,200 =	$13,200
Yearly maintenance	$80 × 11.94 =	+ $955	$100× 11.94 =	+ $1,194
Yearly energy	$900× 11.94 =	+ $10,746	$820× 11.94 =	+ $9,791
LCC		$23,501		$24,185

As the proposed system with a single heater has the lower life-cycle cost, the exception applies and it may be used.

the applicable utility rate structure; the load variations throughout the year; the thermal efficiencies of the equipment (adjusted by load as applicable); parasitic energy usage such as circulation pumps, blowers for forced draft systems and control panels; distribution and standby losses; maintenance costs; and inlet water temperatures.

An analysis of energy costs consistent with the energy cost budget method can be used to justify this exception. Methods for economic calculations are also presented in the Glossary of this chapter.

Distribution Losses

Distribution losses impact building energy use both in the energy required to make up for the lost heat, and in the additional load that can be placed on the space cooling system if the heat is released to the conditioned space. These losses can be limited through two primary strategies: containing the hot water in a storage tank when not required, and insulating the storage vessel and pipes. The requirements of the code differ for circulating and non-circulating systems.

Circulating Systems and Heated Pipes

In circulating systems and systems designed to maintain water temperatures in hot water pipes with heat tape or similar means, the hot water is exposed to loss throughout the entire distribution system. For these systems, the entire distribution piping system must be insulated. Further savings can be realized by controlling the pump or the tape to limit the circulation or heating to those times when hot water is required. As is developed below, there are a number of circulation-control methods available. They differ in their sophistication of predicting or sensing demand.

Insulation

The entire hot water supply and return distribution system must be insulated to the requirements of Table 9-1 of the code. These requirements are summarized in Table 5-D. Note that systems which operate below 105°F are not required to be insulated.

Equivalent thicknesses for insulations of other conductivities are given by the following formula:

$$T = D_{out} \times \left[\left(1 + \frac{t}{D_{out}} \right)^{\frac{K}{0.24}} - 1 \right] \tag{5-A}$$

Table 5-D Minimum Pipe Insulation Thicknesses for Service Hot Water Systems
(from ASHRAE Standard 90.1- 1989 User's Manual)

	Minimum Pipe Insulation Thickness	
Conductivity at 100°F[Btu-in/(h-ft ^{2}-°F)]	Conductivity at 100°F 0.24 to 0.28 [a] [Btu-in/(h-ft^2-°F)]	Conductivity at 100°F 0.28 to 0.30 [b] [Btu-in/(h-ft^2-°F)]
Nominal Pipe Diameter		
Runouts up to 2 in. (<12 ft length)	1/2	5/8
2 in. and less	1	1-1/2
2-1/2 in. and larger	1-1/2	2

[a] Typical of closed-cell foam or high-performance rigid preshaped fiberglass.
[b] Typical of fiberglass wrap.

where

T = minimum required insulation thickness for proposed material (in.)

D_{out} = actual pipe outside diameter (in.)

t = minimum insulation thickness (in.) specified in Table 5-D for a conductivity of 0.24 Btu-in./(h-ft^2-°F)

K = conductivity of proposed material (Btu-in./(h-ft^2-°F)) @ 100°F

Circulation Pump Controls

The code requires automatic circulation-pump controls that are capable of shutting off the pump when hot water is not required. There are primarily three forms of controls that meet this criterion: time clock control; combination time and temperature control; and, demand control.

The simplest complying control system is an automatic time clock. This can be either a stand-alone system or contact controlled through a central energy management system (EMS). Stand-alone timeclocks are available with a wide variety of features. The most important of these is the ability to have multiple schedules such as a separate schedule for each day of the week (the seven-day time clock) or the ability to program in holidays (programmable timeclocks). Most EMS systems will permit the system to operate on a variety of schedules. Time-controlled systems are most appropriate for designs where the hot water usage is fairly constant and predictable. They tend to waste energy both in terms of the pump and heat loss as they will continue to circulate water from the tank whenever the schedule says so regardless of the demand.

Time and temperature systems improve on this scheme by using a temperature sensor to control the pump during the periods in which the time clock is enabled. The temperature sensor shuts off the pump whenever the return water temperature is hot. The system is allowed to sit idle until the return temperature drops to a predetermined limit. Typical systems will use a 20°F deadband and place the temperature sensor on the return line. These systems reduce line losses 10% to 20% by reducing the average temperature of the fluid in the line. They will reduce pump energy by up to 90% depending on the frequency of hot-water demand.

Demand-controlled systems use flow sensors to sense the draw of water from the system. Typically on smaller systems the sensor will be located on the

Example 5-H Calculation of Required Insulation Thickness

Q

A designer wants to use an insulation that has a conductivity of 0.15 Btu-in/(h-ft^2-°F) @ 100°F. What thickness of insulation is required for a 1-1/2 in. copper (1.625 in. o.d.) hot water supply line?

A

As the conductivity is out of the range of Table 5-D, the required thickness will have to be calculated. The value of t, the insulation thickness from Table 5-D, is 1 in.

$$T = 1.625'' \times \left[\left(1 + \frac{1''}{1.625''} \right)^{\frac{0.15}{0.24}} - 1 \right] = 0.57''$$

The insulation on the hot water supply line must be 0.57 in. (roughly 5/8 in.) or thicker.

inlet to the storage tank. On more extensive systems, several flow sensors wired in parallel will be located at each branch off the main loop. On detection of flow, the circulation pump is initiated. The pump can be shut off either through an adjustable interval timer or a temperature sensor located on the return line. Demand-controlled systems will significantly reduce both the line losses and the pump energy.

Controls for Heated Pipes

Systems designed to maintain hot water temperature in pipes, including devices such as heat tape, must be equipped with time switches or some other controls to turn off the system when hot water is not needed.

Non-Circulating Systems

The losses in non-circulating systems are limited through the use of piping insulation to reduce the loss of heat out of the tank through conduction.

Insulation

The first eight feet of outlet piping must be insulated to the requirements of Table 9-1 of the Code. The required level of insulation is the same as that described in the paragraphs above under circulating systems.

Terminal Device Flow Controls

The terminal device flow-control measures reduce energy by reducing waste of hot water. Devices are required that limit and/or meter the flow rate of hot water. Separate requirements are made for public facility restrooms.

Shower Heads

All shower heads except those used in emergency wash stations are required to have integral flow-control devices that limit the total flow to below 2.5 gpm. These devices must be integral to the shower head and be designed to prevent removal. When flow restricting inserts are used, they must either be mechanically retained by the manufacturer or be integral to the design so that the shower head is disabled by their removal. In-line flow controllers may also be used to meet this requirement. Figure 5-C depicts a flow controller.

Sinks and Lavatories

Lavatories in public restrooms are required to limit *both* the flow rate of the hot water *and* the total flow at the faucet.[2]

Total flow can be regulated through occupancy controls. *Occupancy controls* automatically shut off the water when the occupant moves from the fixture. Occupancy controls limit the flow duration, but not necessarily the flow rate. An occupancy sensor (such as depicted in Figure 5-D) or a foot operated self-closing flow switch are examples of occupancy controls. Handicap lavatories are not required to have either type of total flow control device, but still must limit the flow rate of hot water.

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[2] Public-facility restrooms are defined in Article 3 of the Standard as "*a restroom used by the transient public.*"

Figure 5-C Complying In-Line Flow Control Device
(from ASHRAE Standard 90.1- 1989 User's Manual)

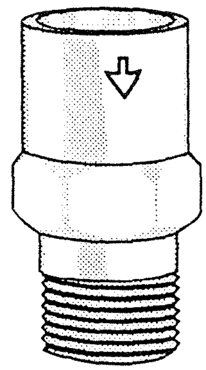
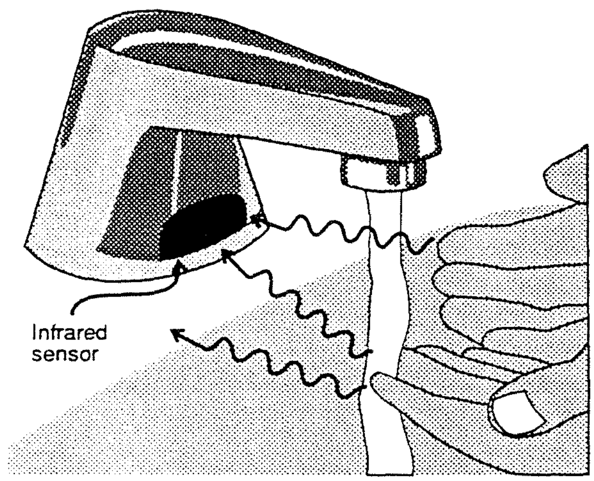


Figure 5-D Lavatory Faucet with IR Occupant Sensor
(from ASHRAE Standard 90.1- 1989 User's Manual)



The flow rate must be no greater than 0.5 gpm in public lavatories unless a device such as a foot switch or occupancy sensor is present, when the maximum flow rate is 0.75 gpm.

All lavatories in public restrooms shall have temperature control devices that limit the outlet temperature to 110°F maximum.

All other lavatories are required to limit the flow rate to the faucet at or below 2.0 gpm. The total flow of hot water at these fixtures is not regulated. Though not required, the provisions for hot-water flow control for public lavatories are applicable as conservation measures to non-public lavatories as well.

Sinks, in all facilities, are only required to limit the flow rate at the faucet – the flow must be controlled at or below 2.5 gpm.

Table 5-E summarizes these flow control requirements for sinks and lavatories.

Table 5-E Summary of Required Flow Controls
(adapted from ASHRAE Standard 90.1- 1989 User's Manual)

	Hot Water Flow Rate Limits	Total Flow Control Type and Limits
Public Lavatories[a]		
Handicap	≤ 0.5 gpm	N.A.
	≤ 2.5 gpm	Self-closing or metering valve
Non-handicap	≤ 0.75 gpm	Occupancy sensor or foot switch
Other Lavatories	≤ 2.0 gpm	N.A.
All Sinks	≤ 2.5 gpm	N.A.

[a] Lavatories in public facility restrooms shall have controls which limit outlet temperature to 110°F.

Swimming Pools and Spas

Pools and spas have several requirements: solar or heat pump heating must be used, the heater must meet the requirements of Table 11-1 for minimum thermal efficiency, and the heater must be provided with specific on/off controls.

Pool Heating

If a swimming pool is heated, then it must use active solar or heat pump heating. Gas or electric resistance heating are allowed only if they can be shown to provide lower annual energy costs than the solar or heat pump systems.

In addition, all pool heating equipment must meet the minimum efficiency requirements of Table 11-1 in the Code. In practice, this requirement is relevant only if gas or oil pool heating are used.

Solar heating systems are especially efficient at producing the low temperature water required for pool heating. Heat pumps are also very efficient and provide an alternative to solar pool heating when space for solar collectors is not available.

Controls

There are two types of controls required for each pool or spa heater: an accessible manual on/off switch and an automatic adjustable time switch.

The manual on/off switch must be a dedicated switch or contact. The thermostat setpoint adjustment may not be used to satisfy this requirement. Furthermore, for gas- or oil-fired heaters, use of the manual on/off switch shall not require manual reignition of the pilot. This requires use of either a standing pilot or a pilotless ignition system. The purpose of these requirements is to encourage the occupants or maintenance personnel to disable the heater whenever it is not needed. For that reason, the switch must be *readily accessible* and easy to use.

For pools in public facilities, the manual on/off switch may be in a locked control panel so that it is not accessible to the public. However, facility staff must have access to the control panel at all times.

A time switch must be provided for all pool pumps. These time switches must be capable of shutting down the pumps during the periods of peak utility electrical demand. Pumps may operate within the peak period as required to circulate water through filters and chemical treatment; the controls on the pump, however, must be capable of minimizing its operation during peak periods. Exceptions are provided for pumps that must operate continuously to meet public health standards and pumps that operate to use solar or waste heat recovery to heat the pool.

Spring-wound timers may be used to meet these requirements. Automatic programmable timeclocks will meet the requirements and will also help reduce energy costs through automatic demand control.

Glossary

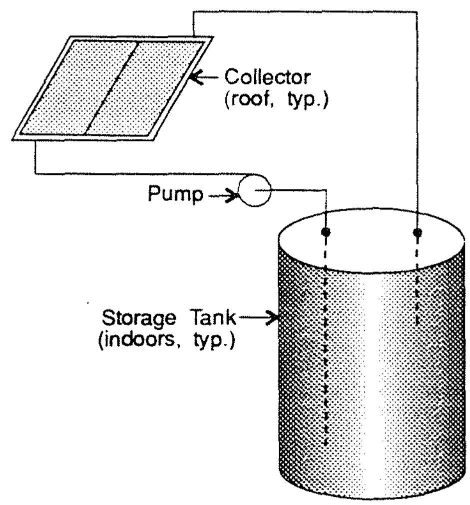
Definitions

Definitions and concepts that are used throughout this chapter are reviewed here as a reference.

Active Solar Water Heating Systems

use a pump to circulate either potable water or another heat transfer fluid through the collectors.

Figure 5-E Active Solar Water Heating System



Backup Water Heaters

provide supplementary heating when the primary system is not functioning or cannot meet the water heating load. They are generally associated with solar water heating systems, where an electric resistance heating element in the storage tank or a separate electric resistance water heater is often used.

Booster Heaters

are water heaters which raise the water temperature of service hot water for special high-temperature requirements such as sterilizers or dishwashers.

Circulating Systems

are hot-water distribution systems that circulate hot water through the distribution system either intentionally or unintentionally. Typical circulating systems will be provided with a circulation pump and hot-water return lines.

Cogeneration

is electrical power generated on-site, whose waste heat can be used to eat service water. In general cogeneration systems are cost effective only in applications which have large and rather constant hot water or steam loads. Service-hot water systems for hotels, health-care facilities or sports facilities with large pools are all potential candidates. In preparing an economic evaluation of a cogeneration system, the following items should be carefully considered: development of accurate hourly load profiles; the cost of power conditioning and isolation of sensitive circuits; the cost of maintenance; the availability of coincident electrical loads; the availability of utility excess power purchasing and their requirements for power conditioning; and the economics of other high efficiency heat-generating alternatives.

Energy Factor (EF)

is a measurement of the combined effects of recovery efficiency and standby losses. It is determined through the DOE test procedure 10 CFR Part 430 which is applicable to the smaller equipment covered by NAECA (see NAECA). The water heater is placed in a controlled environment which is maintained between 65°F and 70°F. The inlet water temperature is maintained at 58°F, and the average tank temperature is maintained at 135°F. The test begins after the heater reaches a stable condition. Over the period of 24 hours, the energy input to the heater is recorded. During the test period, six equal draws of water totaling 64.3 gallons are made at one-hour increments. The energy factor is the ratio of the thermal energy transferred to the water, to the energy input to the heater throughout the test period.

First Hour Rating

is a measure of the combined heater and storage capacity. It is the maximum draw of water that can be obtained from a unit with a fully charged tank without an appreciable drop in outlet temperature. First-hour ratings are used in the selection of residential units.

Heat Recovery

Refrigerant heat recovery systems should be considered where simultaneous cooling and water heating are required. They are most cost effective where the water heating loads are large and well distributed throughout the day. Typical applications are hotels, mixed use retail/residential projects, commercial kitchens and institutions such as jails and hospitals.

Heat-recovery systems for water heating can be broadly split into two categories: those that recover heat from condenser or chilled water loops and those that act like water-cooled condensers. Both types of systems can provide service water temperatures up to 140°F. Health and plumbing codes require that both systems use double-wall heat exchangers or other approved means to avoid contamination of potable water by either refrigerant or condenser water.

Condenser water source systems utilize a water-to-water heat pump which lifts the heat from the condenser or chilled water loop and uses it to charge a storage tank. These systems have COPs in the range of three to six, depending on the temperatures of both the source chilled or condenser water and the service hot water. In addition to producing hot water at such high efficiency, they save energy by reducing operation of the cooling tower and/or providing cooler condenser water temperatures. They are placed in the loop upstream of the cooling tower and act as a first stage of heat rejection when in operation.

Auxiliary condenser systems draw heat directly from the refrigerant. Included in this class are double-bundle chillers and refrigerant desuperheaters. Both of these systems operate on the same principle: hot refrigerant gas on the way to the normal condenser is diverted through the auxiliary water heating condenser as a first stage of cooling. Refrigerant desuperheater kits are available with a wide range of controls, capacities and circuiting options. They can be used with refrigerated casework, commercial freezers and refrigerators, direct expansion air-conditioning units and heat pumps.

Figure 5-F Service Water Heating with Heat-Recovery Heat Pump
(from ASHRAE Standard 90.1- 1989 User's Manual)

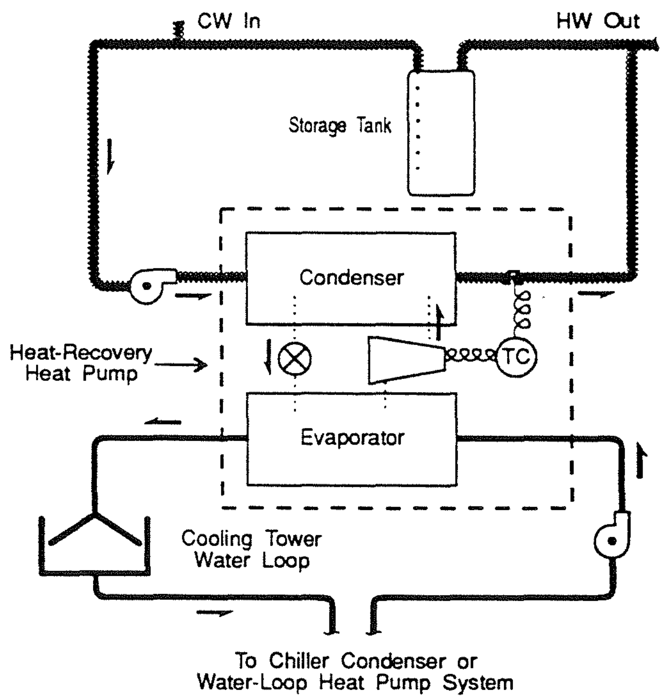


Figure 5-G Service Water Heating with Double Bundle Chiller
(from ASHRAE Standard 90.1- 1989 User's Manual)

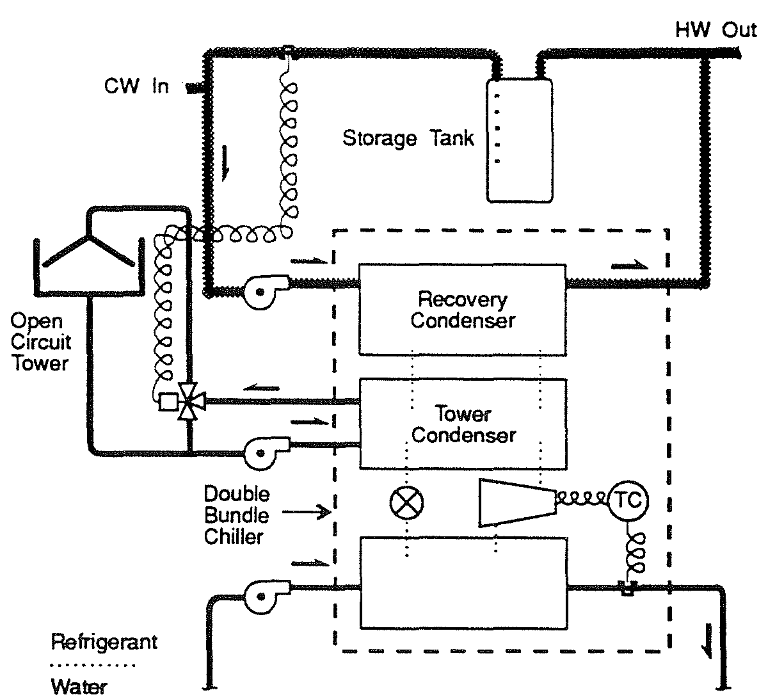
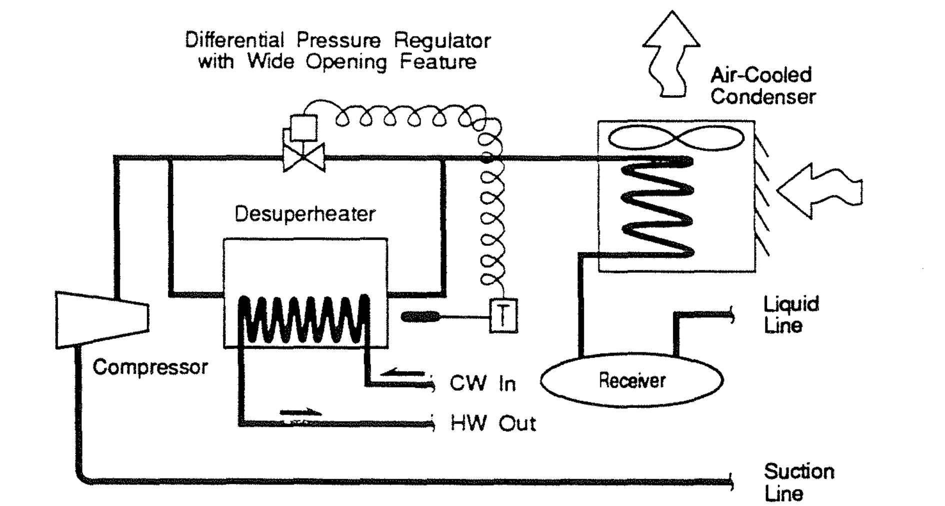
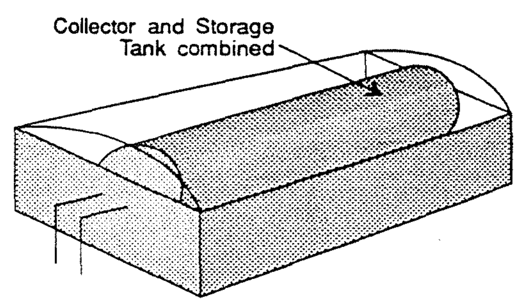


Figure 5-H Service Water Heating with Refrigerant Desuperheater
(from ASHRAE Standard 90.1- 1989 User's Manual)



Integral Collector Storage Solar Water Heating Systems — store the heated water in the collector.

Figure 5-I Integral Collector Storage (ICS) System



Metering Valve — is a device which allows a specified volume of water to flow through it on each request. A spring-actuated, self-closing faucet valve is a metering device.

NAECA — the National Appliance Energy Conservation Act of 1987, is a federal standard that specifies the minimum performance of residential space-heating, space-cooling and water-heating equipment. For water heaters this includes:

- Electric heaters: all types at or below 12 kW input (including heat-pump water heaters and instantaneous heaters)
- Fuel-fired storage heaters: at or below 75 kBtu/h input for gas, 105 kBtu/h input for oil
- Fuel-fired instantaneous heaters: at or below 200 kBtu/h input for gas, 210 kBtu/h input for oil
- All fuel-fired pool and spa heaters

Point of Use Heaters — are water heaters that are located within a few feet of the terminal device or devices that use the hot water. They can be either the instantaneous type (flash heaters) or storage type (tank heaters).

Process Energy	is "...energy consumed in support of manufacturing, industrial or commercial processes not related to the comfort and amenities of the building's occupants." Examples of process water heating include: hot water used for sterilizing in canning operations; heating of chemical baths in a production facility; and, hot water used in the production of pharmaceuticals.
Real Discount Rate	represents the interest rate on a loan (or bond) that is adjusted to account for inflation and tax effect. It is used in economic calculations of alternative investments as described in the following section.
Recovery Efficiency	is similar to thermal efficiency. It is the ratio of thermal energy transferred to the water to the energy input to the heater. In this case, the heater is initially filled with cold water. The test period extends until the entire volume of water in the heater is fully charged to the design hot water supply temperature.[1]
Recovery Load	is the amount of energy which must be added to the water in order to satisfy the user's hot water needs.
Recovery Rate (or Recovery Capacity)	is the rate at which a heater can produce hot water on a continuous basis. This is a measure of capacity used to select water heaters for commercial and industrial systems. The recovery rate of a heater will vary with the temperature range under which it operates. In Hawaii it usually is 60°F to 70°F.
Service Water Heating	is "...the supply of hot water for purposes other than comfort heating or process requirements." Water heating for commercial kitchens, laundries, car washing, snow/ice melting and beauty salons is included in the requirements of service water heating.
Solar Water Heating	Solar heating is best suited to projects where large quantities of low-temperature hot water are required, coupled with available space for collector arrays. Pools are an excellent application as the required temperatures are low (permitting the use of low-cost and durable unglazed collectors) and the mass of water in the pool buffers the temperature swings. Other applications where solar should be considered include preheat of water for use in locker rooms, low-temperature process heating and preheat of water for commercial laundries.
Standby Loss	is the amount of heat loss from a water heater while the heating element, burner or compressor is not operating. Standby loss includes pilot light energy as well as heat loss through the tank and fittings and up the flue (for gas water heaters). For some water heaters it is specified in %/hr, the percent of the energy content of the hot water in the tank which is lost each hour. Typical values are 4% for gas water heaters and 1% for electric resistance water heaters, but the values vary significantly between different models.
Subcooling of Steam Condensate	In steam systems, a heat exchanger upstream of the condensate receiver tank can be used for the dual purpose of heating service water and subcooling condensate to prevent flashing. Without subcooling, a portion of the heat in the condensate will be lost in the form of flash steam vented from the tank. By

[1] From ASHRAE HVAC Applications Handbook (1991), Chapter 44.

subcooling the steam, this energy is captured and put to good use. As the demands for steam and hot water are not likely to coincide, a storage-type system (such as a shell and tube heat exchanger) is generally recommended.

Terminal Device

is a fixture or appliance that uses hot water, such as faucets, dishwashers and showers.

Thermal Efficiency

is the ratio of the thermal energy transferred to the water to the energy input to the heater at a 70°F water temperature rise. It is measured under steady-state conditions with a constant draw of water.

Input and output energy are expressed in the same units so that the result is non-dimensional.

(5-B)

$$E_t\,(\%) = \frac{Q_{Fluid}}{Q_{Fuel}} \times 100$$

where

E_t = thermal efficiency

Q_{Fluid} = heat transfer rate to the air or water

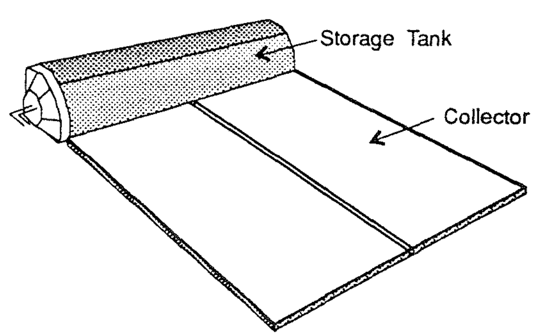
Q_{Fuel} = heat content rate of the fuel consumed

Thermal efficiency includes the effects of standby losses. It is measured under specific test conditions.

Thermosiphon Solar Water Heating Systems

use natural convection to move water or other heat transfer fluid through the collector. A circulation pump is not used.

Figure 5-J Thermosiphon Solar Water Heating System



Economic Calculations

For some requirements, there are exceptions on the basis of economic calculations. The calculations are specified to consider equipment installed cost, maintenance costs and energy costs over the lifetime of the equipment. Although there are a number of economic models that can be used for this sort of comparison, one of the most widely accepted is the life-cycle-cost method (LCC). LCC is a representation in present dollars of the cost of an investment over the lifetime of that investment. It is useful for evaluating mutually exclusive alternatives that have the same anticipated lifetime.

A *discount rate* is required for a life-cycle-cost calculation. The discount rate represents the cost of capital to building owners. In essence it is the rate on a loan (or bond) adjusted to account for inflation and taxes. High discount rates will discourage investments. A 3% real discount rate is typical for energy policy analyses. Higher rates are often used by private investors for use in their economic evaluation of commercial construction.[2] The U.S. Department of Energy has proposed a 4.5% discount rate for federal agency in-house energy management programs.[3] This rate is calculated from the long-term bond rate (8.5% at the time) minus the inflation rate (4%).

Life-cycle cost is calculated by determining the present worth of the cost of an investment. For water heating alternatives it will look like this:

(5-C)

$$LCC = IC + ESPWF \times \left(COST_{Energy} + COST_{Maintenance}\right)$$

where

LCC = life-cycle cost
IC = initial cost premium of the alternative
ESPWF = equivalent series present worth factor (from Table 5-F)
$COST_{Energy}$ = yearly energy cost saving
$COST_{Maintenance}$ = yearly maintenance cost reduction

The equivalent series present worth factor varies with the discount rate and the project lifetime. Table 5-E presents these factors for a number of combinations.

ESPWF for other lifetimes and discount rates can be found from tables in most engineering economics texts or calculated from the formula:

(5-D)

$$\mathrm{ESPWF} = \left[\frac{(1+d)^n - 1}{d \times (1+d)^n}\right]$$

where

n = lifetime of the measure
d = discount rate
ESPWF can only be used when the annual costs remain constant.

For two alternative systems, the one with the smaller LCC is the best investment.

---

[2] Take care to account for inflation and fuel escalation either through lowering the discount rate or through inflating future energy and maintenance costs.

[3] Notice of Proposed Rulemaking, Federal Register, January 25, 1990. This rate is presently 7% until a final rulemaking is published.

Chapter 33 of the ASHRAE HVAC Applications Handbook (1991) outlines procedures for detailed economic analyses. There are also data presented on expected equipment service life.

Table 5-F Present Worth Factors
(from ASHRAE Standard 90.1- 1989 User's Manual)

	Discount Rate							
Lifetime (yrs)	2.5%	3.0%	3.5%	4.0%	4.5%	7%	10%	15%
7	6.35	6.23	6.11	6.00	5.89	5.39	4.87	4.16
8	7.17	7.02	6.87	6.73	6.60	5.97	5.33	4.49
9	7.97	7.79	7.61	7.44	7.27	6.52	5.76	4.77
10	8.75	8.53	8.32	8.11	7.91	7.02	6.14	5.02
15	12.38	11.94	11.52	11.12	10.74	9.11	7.61	5.85

Example 5-I Life-Cycle Cost Analysis

Q

Two alternative gas-fired water heaters are being considered for a project: a standard-efficiency model and a high-efficiency model both from the same manufacturer. Both are of equal construction and estimated to have a 10-year lifetime. Using a 3% discount rate and the estimated cost data from the table below, which model should be selected?

A

From the table above, the ESPWF is 8.53.

	Standard Model			High Efficiency Model		
Costs	Actual		Present Worth	Actual		Present Worth
Installed	$1,940	=	$1,940	$2,310	=	$2,310
Yearly Maintenance	$10	× 8.53 =	+ $85	$10	× 8.53 =	+ $85
Yearly Energy	$630	× 8.53 =	+ $5,374	$530	× 8.53 =	+ $4,521
LCC			$7,399			$6,916

The lower LCC of the high-efficiency model makes it the better choice.

6. Cost Budget Method

General Information

Overview

This chapter explains how to use the energy cost budget method to meet the requirements of the Hawaii Model Energy Code. This method applies to two situations:

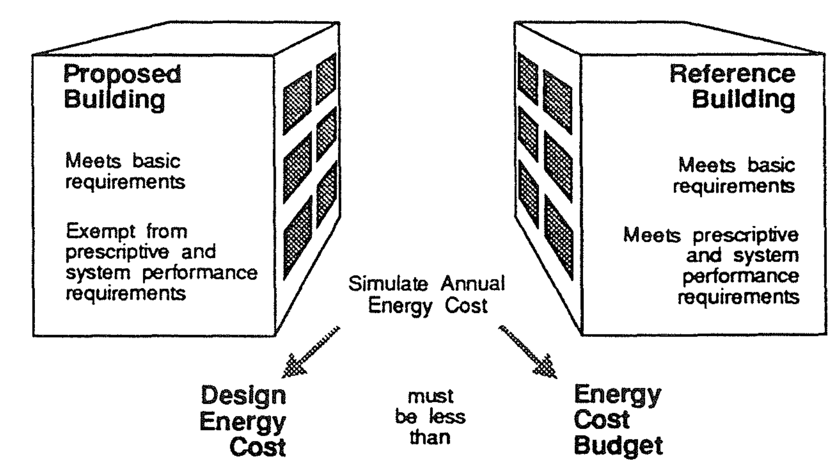
- The proposed building cannot meet either the prescriptive or system performance criteria of one or more of Articles 6 (lighting), 8 (envelope), 9 (HVAC systems)
- The designer prefers this method because of its greater flexibility and the opportunity for innovative design

The Code recommends the energy cost budget method over the prescriptive and system performance methods for evaluating proposed design alternatives and encourages the designer to view the ECB method as a design tool to achieve the most energy-efficient and cost-effective design and *not* solely as a last resort. An ECB method shows the interaction of *most* building components and systems, while the prescriptive and system performance methods set minimum performance levels for building components and/or systems.

Another important advantage of the ECB method is that it permits the designer to evaluate not only compliance, but the margin by which a project complies. This margin is currently used by many utilities as a basis for conservation rebates.

Note that familiarity with a building energy simulation program is necessary to use this method. This chapter provides guidelines for modeling a building and

Figure 6-A Energy Cost Budget Method



for determining compliance, but it does not include instructions for using a specific computer program.

Basic Requirements

Although the ECB method permits trade-offs in energy use between different components of the building, the proposed design must still comply with the basic requirements of Articles 5 through 12. For instance, the air leakage requirements of Article 8 apply to air conditioned buildings, even if the project uses the energy cost budget method. The basic requirements still apply with the energy cost budget method for several reasons.

- Many basic requirements cannot be accurately modeled (such as sub-division of feeders)
- Many are inherently cost effective (such as energy efficient motors)
- Some basic requirements are calculation methodologies which establish a fair basis for comparing component performance (such as U-value calculations).
- Some are not intended for trade-offs (such exterior lighting)

Limitations for Speculative and Shell Buildings

Shell buildings (buildings in which the occupancy is not known at the time of the design) may *not* use the energy cost budget method. Shell buildings must use the prescriptive or system performance methods. The ECB method may be used, however, with speculative buildings (a partially completed project in which the occupancy is known at the time of the building permit application). However, special rules apply.

Overview of Procedure

Compliance is achieved when the annual operating cost for the proposed design is less than or equal to the annual operating cost for a budget building (reference building). The proposed design may deviate from the prescriptive and system performance criteria. The budget building is similar to the proposed building in size and usage, but meets the prescriptive or system performance criteria of Articles 5 through 12.

The annual operating cost must be calculated by applying the applicable local utility rates to the calculated monthly (or hourly) energy demands and consumption. Average or typical rates are *not* to be used. The application of the rates must include such factors as demand charges, rate blocks, time-of-day brackets, fuel adjustment charges and surcharges.

Climate Data

The weather data used with the simulation program must be appropriate for the site and for the complexity of the energy conserving features of the proposed design. Hourly weather data are available for four locations in Hawaii: Honolulu, Hilo, Barbers Point and Lihue. These data are acceptable for use with hourly simulation models. Summaries of these data are included in Appendix D of this Manual.

The hourly data for Honolulu is a Typical Meteorological Year (TMY). TMY data are compiled from rigorous statistical sampling of hourly data over a period of many years. The Honolulu data is, therefore, of better quality than the other hourly weather data and may be used throughout the islands. The data for the other locations is for a single year and may not represent long term average conditions.

Temperature bin data are available for Barbers Point. Bin data can also be generated from the hourly data files described above. Bin data consists of the average number of hours that the drybulb temperature falls within 5-degree temperature ranges (bins). Before such data can be used, the designer must determine whether a simplified calculation procedure that uses bin weather data is acceptable for the building in question (see the discussion below entitled "Choosing the Simulation Tool").

Modeling Rules

This section describes the methods and assumptions to be used in calculating the annual design energy cost (DECOS) of the proposed building, and the annual energy cost budget (ECB) of the budget building. This section also describes the features of each of the buildings. The information is organized in three columns. The first column is the topic. The second column is the modeling rules for the proposed design and the last column has the modeling rules for the budget or reference building. The modeling rules are also grouped into four categories: building envelope, lighting and internal gains, HVAC, and hot water systems.

Building Envelope

This set of modeling rules applies to the building envelope of the proposed building and the reference building.

	Proposed Design	*Budget Design*
Building Shape	Model the proposed building as it is designed.	The reference building is identical to the proposed design except building components must comply with the prescriptive or systems performance requirements.
Roof Constructions	Model the roof constructions as they appear on the plans and specifications.	The roof shall be a light-weight construction with a RHGF of 0.05 consisting of an absorptivity of 0.70, a U-value of 0.0714 Btu/h-ft^2-°F and no radiant barrier.
Skylights	Model the skylights as they appear on the plans and specifications.	Same type of skylight as the proposed design, except skylight area may not exceed the limit specified in Section 8.4(d) of the Code.

Wall Constructions	Model the wall constructions as they appear on the plans and specifications.	It is always acceptable to model a lightweight wall with a U-value of 0.10 Btu/h-ft^2-°F in the reference building. Otherwise, model the same construction type as in the proposed design, but with a U-value of 0.15 Btu/h-ft^2-°F for metal framed walls and 0.10 for all others (except walls with heat capacity greater than 7.5 Btu/°F-ft^2 should be uninsulated in the budget building). Wall absorptivity shall be assumed to be 0.70 and the wall is assumed to be unshaded.
Floor Constructions	Model the floor constructions as they appear on the plans and specifications.	Same as the proposed design
Envelope and Ground Absorptivities	Model the absorptivities of the proposed design if they are known. Otherwise, assume 70%. Assume 20% absorptivity for the ground.	Assume 70% absorptivity for all exterior walls and roof elements. Assume 20% absorptivity for the ground.
Fenestration (windows)	Fenestration shall be modeled as it is shown on the plans and specifications, including consideration of overhangs and sidefins.	Fenestration shall have the same area and orientation as the proposed design, but the glass shading coefficient shall be set to the RSHG requirement of either Table 8-5 or 8-6 of the Code. (See Chapter 3 also). Fenestration with an orientation within 45° of north shall have the RSHG requirement for north.
Interior Shading Devices	A medium-colored venetian blind may be assumed as the default, even if the plans and specifications do not show interior shading devices. When closed, the default interior shade shall be assumed to reduce the shading coefficient to 80% of the shading coefficient when the shade is open.	If the default is used for the proposed design, it must also be used for the budget building.
	Interior shading devices may be ignored for the proposed design.	If so, they should also be ignored for the budget building.

	If the plans show interior shading devices that perform better than the default medium-colored blind, these can be modeled. The performance of the shading device may be taken from the manufacturers literature.	The default medium-colored blind shall be modeled (see above).
Window Management	If the analysis model has a window management algorithm, manually operated shades may be assumed to close when solar gain through the window exceeds 30 Btu/h-ft^2 and open when solar gain drops below this threshold.	Same as proposed design.
	If the analysis model does not have a window management algorithm, assume that half the blinds are closed continuously.	Same as proposed design.
	If the proposed design has special controls for interior shading devices, these controls may be modeled.	Assume that blinds close when solar gain through the window exceeds 30 Btu/h-ft^2 (the default).
Overhangs and Sidefins	Model fixed shading devices as shown on the plans.	No overhangs or sidefins
Exterior Shading Devices	If the proposed design has specially designed exterior shading devices such as moveable sunscreens, louvers or canopies, these may be modeled in the proposed design, including special controls that are part of the design.	No exterior shading devices.
Shading from the Site	Shading from buildings, trees or terrain that are expected to remain for the life of the building may be modeled for the proposed design.	The same shading conditions are modeled for the budget building.
Infiltration	The actual infiltration rate of the proposed design may be used if it is known. Otherwise, model infiltration the same as the budget building.	A constant infiltration rate of 0.038 cfm/ft^2 of exterior wall area shall be assumed for the perimeter zones only. In non-residential buildings, infiltration shall be scheduled only for those hours when the HVAC system does not operate. In hotels, motels and residential buildings, infiltration shall be scheduled at all times.

Lighting and Internal Gains

This set of modeling rules apply to lighting and other internal heat gains for both the proposed building and the reference building.

	Proposed Design	*Budget Design*
Lighting Power	Use the connected lighting power of the proposed design. If qualifying automatic controls are installed, the adjusted lighting power may be used (see below). For speculative buildings, use the same lighting power as the budget building.	Determine the lighting power using either the prescriptive or systems performance method. If the prescriptive method is used, assume that the lighting power is uniformly distributed throughout the zones. If the systems performance method is used, distribute the lighting power by zone according to the system performance allocations.
Daylighting Controls	Model daylighting controls if they are included in the plans and specifications and the analysis tool is capable of modeling daylighting. If the proposed design has daylighting controls, but the analysis tool cannot model daylighting, the lighting power control credits may be taken from the proposed design (see Table 6-3 of the Code)	No daylighting controls.
Other Automatic Lighting Controls	Adjust the connected lighting power by the control credits in Table 6-3 of the Code, when qualifying automatic controls are part of the proposed design.	No automatic controls.
Occupancy Load	Use the occupant load for the proposed design if it is known. Otherwise select an occupant load from Table 13-1 of the Code.	Same as proposed design
Receptacle Load	Use the receptacle load for the proposed design if it is known. Otherwise select receptacle load from Table 13-2 of the Code.	Same as proposed design
Internal Load Schedules	Use the operating schedules for the proposed design if they are known. Otherwise, use the schedules from Table 13-5 of the Code for the closest occupancy type. Use the lighting schedule from Table 13-5 for both lighting and receptacle loads.	Same as proposed design.

Example 6-A Using Table 6-5 to Find an Adjusted ULPA – Office Building

Q

A four-story office building measures 60.2 ft × 152.8 ft from the inside of the exterior walls. 800 ft^2 on each of the four floors will be unconditioned. What value of unit lighting power should be used for the conditioned floor area in the reference simulation?

A

The Gross Lighted Area of the building is:

$$GLA = 60.2\ ft \times 152.8\ ft \times 4\ floors = 36{,}794\ ft^2$$

Table 6-5 shows that the ULPA for an office building of this size is 1.65 W/ft^2. Therefore, the Lighting Power Allowance is:

$$LPA = 36{,}794\ ft^2 \times 1.65\ W/ft^2 = 60{,}710\ W$$

The conditioned floor area is:

$$CFA = 36{,}794\ ft^2 - 800\ ft^2 \times 4\ floors = 33{,}594\ ft^2$$

If an allowance of 0.8 W/ft^2 is made for the unconditioned space, the LPA for the conditioned floor area would be:
ALPA = 60,710 W - 3,200 ft^2 × 0.8 W/ft^2 = 58,150 W
The adjusted ULPA to be used in the simulation of the conditioned zones of the reference building would be:

$$AULPA = 58{,}150 / 33{,}594 = 1.73\ W/ft^2$$

The remaining 2,560 W of lighting energy must be accounted for in the model, but will not add heat to the conditioned zones.

Example 6-B Using Section 6.5 to find an adjusted ULPA – Office Building

Q

An office building has the following distribution of total floor area, with all office functions classified as "Reading, Typing and Filing:"

Enclosed offices (Category I) at 180 ft^2 each, 9 ft ceiling	52%
Open offices (Category II)	20%
Corridors	20%
Unlisted space	8%

What would be the average Unit Lighting Power Allowance for the gross lighted area and for the conditioned area?

A

Using Table 6-6a to establish the UPD, and Figure 6-1 to establish the area factor (AF), the values for each type of area would be:

Example 6-B Using Section 6.5 to find an adjusted ULPA – Office Building (Continued)

Category I offices:	UPD = 1.8 W/ft^2,	AF = 1.4
Category II offices:	UPD = 1.9 W/ft^2,	AF = 1.0 (note b)
Corridors:	UPD = 0.8 W/ft^2,	AF = 1.0 (note b)
Unlisted space:	UPD = 0.2 W/ft^2,	AF = 1.0 (none given)

Therefore, the average ULPA for the GLA would be:

$$UPD = 0.52 \times 1.8 \times 1.4 + 0.20 \times 1.9 + 0.20 \times 0.8 + 0.08 \times 0.2 = 1.87 \text{ W/ft}^2$$

The average ULPA for the conditioned area would be:

$$UPD = 0.52 \times 1.8 \times 1.4 + 0.20 \times 1.9 + 0.20 \times 0.8 = 1.85 \text{ W/ft}^2$$

While this value is slightly higher than the adjusted 1.73 W/ft^2 (for conditioned spaces) determined from Table 6-5 in Example 6-A above, the benefit of the higher value in setting the ECB of the prototype building would have to be weighed against the extra effort to do the detailed layout of the prototype building.

Example 6-C Lighting Power Value for a Proposed Design – Adjustment for Daylighting Controls

Q

A designer plans to use 2.25 W/ft^2 of lighting power in a perimeter zone, but 50% of the lights will be controlled by a two-step (on/off) daylight sensing control device. What unit lighting power value should be used in the model of the proposed design?

A

The designer actually has two options for modeling the lighting in the perimeter zone of the proposed building:

1. The power adjustment factor (PAF) from Table 6-3 for this type of control is 0.1. This PAF can be applied to 50% of the lights in this zone. The resulting adjusted unit lighting power (ULP) is:

$$ULP = 2.25 - 2.25 \times 0.5 \times 0.1 = 2.14 \text{ W/ft}^2$$

The hourly operation profiles would then be the same as used in the budget building, and the daylight-sensing control device would *not* be modeled.

2. The proposed design can be modeled with the full 2.25 W/ft^2 of lighting power, and the daylight sensing control device can be modeled to turn off 50% of the perimeter lights when there is adequate daylighting.

In either case, no adjustment for daylighting controls is modeled in the budget building.

HVAC Systems and Equipment

This set of modeling rules applies to the HVAC system for both the proposed building and the budget building.

	Proposed Design	*Budget Design*
HVAC System for spaces that are air conditioned	Model the HVAC system as shown on the plans and specifications.	Model the same system type as in the proposed building, but one that exactly complies with Articles 9 and 10. If the proposed system type is not allowed under the requirement of Articles 9 and 10, then choose a similar complying system.
	If no equipment is shown on the plans and specifications (for instance speculative buildings where the tenant will install the system), make reasonable assumptions about the system and equipment characteristics. Document the assumptions for future compliance.	Model the same system type as in the proposed building, but one that exactly complies with Articles 9 and 10. If the proposed system type is not allowed under the requirement of Articles 9 and 10, then choose a similar complying system.
HVAC System for spaces that are *not* air conditioned	If the envelope enclosing the unconditioned spaces meets the prescriptive or system performance criteria, then no HVAC systems are assumed for the unconditioned spaces and they drop out of the thermal simulation model.	No HVAC system
	If the envelope enclosing the unconditioned spaces does not meet the prescriptive or system performance criteria, then assume that there is an HVAC system serving the unconditioned spaces. Make reasonable assumptions about the HVAC system and equipment, which must meet the requirements of Article 9 and 10.	Same as the proposed design.

HVAC Zones Nonresidential	Create thermal zones for the proposed design that correspond to the zones served by the HVAC system. Similar zones may be grouped for modeling purposes. There should generally be at least five zones for each floor: an interior zone and four perimeter zones. The interior zone can be eliminated, however for buildings that are less than 30 ft wide. Also light manufacturing, assembly and warehouse spaces may be modeled as a single zone if so controlled.	Same as the proposed design
HVAC Zones Residential	At least one zone per dwelling unit, but multiple zones may be created for dwelling units that have suitable controls.	One zone per dwelling unit.
HVAC Operation	Use the schedule for the proposed building or select a schedule from Table 13-5 of the Code based on the occupancy that is most similar.	Same as the proposed design
Thermostat Setpoint	75°F for cooling	Same as the proposed design
HVAC Equipment and Component Performance	Model the equipment and components shown on the plans and specifications.	Equipment and components should be upgraded or downgraded to meet the exact requirements of Article 10 of the Code.
Process Equipment and Loads	Known process loads should be modeled to allow equipment that might serve combined conditioning and process loads to be properly sized and the energy costs calculated at the proper utility rate steps.	The same process loads must be included in the budget building.
Equipment Sizing	All air flows, water flows and equipment capacities must be modeled as specified on the plans; however, if process loads are not modeled, then equipment capacity may be reduced accordingly. It is not acceptable to allow the analysis tool to automatically size components or equipment.	Equipment shall be sized to meet the requirements of Article 9.4(a) without using any of the exceptions to 9.4(a). If process loads are included in the proposed design, the equipment shall be sized according to 9.4(a) to meet both the process and space conditioning loads.

Outside Air Ventilation	Model the outside air ventilation as designed.	Model outside air ventilation either the same as the proposed design or as in ASHRAE Standard 62-1989, whichever is greater. Outside air must be completely shut off during setback, warm-up and unoccupied periods.
Redundant Equipment	Equipment for backup or emergency services may be ignored if it is controlled such that it will not be operated during normal building operation.	Same as the proposed design.
Dehumidification	Model the system as designed.	If subcooling of the supply air is required for dehumidification, then reheat for the budget building must be provided from recovered waste heat (such as condenser heat recovery).

Example 6-D Use of Default Values

Q

The designer of an office building anticipates an occupancy of 200 ft^2/person. The default design occupancy for an office building in Table 13-1 of the Standard is 275 ft^2/person. What value should be used in the simulation of the reference and the proposed buildings?

A

The actual value of 200 ft^2/person should be used. Furthermore, the same value must be used in both building models. Since the proposed design is based on the more dense 200 ft^2/person, a more realistic representation of the operation of the HVAC system will result from using this density in the simulation.

Example 6-E Hourly Internal Load

Q

What is the default occupant load in a 1,000 ft^2 office space at 10 a.m. on a weekday?

A

From Table 6-A, the default occupant density is 275 ft^2/person. Each occupant generates 230 Btu/h of sensible load and 190 Btu/h of latent load. From Table 13-5 of the Standard the default schedule percentage multiplier for 10 a.m. on a weekday for an office building is 95%. The load in the space is given by:

$$\text{\# of Occupants} = \frac{1{,}000\,\text{ft}^2}{275\,\dfrac{\text{ft}^2}{\text{Person}}} = 3.64\,\text{people}$$

$$Q_{\text{Sensible}} = 3.64\,\text{people} \times 230\,\frac{\text{Btu}}{\text{h} - \text{person}} \times 0.95 = 794.5\,\frac{\text{Btu}}{\text{h}}$$

$$Q_{\text{Latent}} = 3.64\,\text{people} \times 190\,\frac{\text{Btu}}{\text{h} - \text{person}} \times 0.95 = 656.4\,\frac{\text{Btu}}{\text{h}}$$

Example 6-F Adjusted Occupant Loads – Office Building

Q

The actual occupancy of a project is not known. To be safe, the designer sizes the HVAC systems using an assumed occupant density of 110 ft^2/person which he obtains from the ASHRAE Pocket Handbook as a recommended average office occupant density. What value should be used in the simulation of the project for compliance with Article 13?

A

The default value from Table 6-A for an office building is 275 ft^2/person. Although the design value of 110 ft^2/person may be reasonable for system sizing purposes where actual occupancy is not known, it does not necessarily represent an average condition. In lieu of more project specific information the default occupancy (275 ft^2/person) should be used.

Example 6-G Selection of Reference HVAC Systems and Equipment

Q

A proposed office building is to use a constant volume air conditioning system with electric reheat. What type of system should be modeled in the reference building?

Example 6-G Selection of Reference HVAC Systems and Equipment (Continued)

A

The proposed system is not allowed by Section 9.4(b) of the Code, which does not allow reheating except under certain conditions. Therefore, the reference building cannot use the same system type, but must use a similar system which complies with the prescriptive requirements. Options include a constant volume system with at least 75 percent of the energy for reheat or mixing provided from recovered or solar sources (exception 9.4(b)(2)(C)) or a variable air volume system meeting the description in 9.4(b)(2)(A). See Section 9.4(b)(2) for other exceptions.

Example 6-H Reference HVAC System Sizing

Q

Design load calculations on a zone of a reference school building have indicated a peak heating requirement of 360,000 Btu/h and a peak cooling requirement of 36 tons. What coil capacities should be used in the reference model?

A

The unit capacities should match the design loads, but can include pick-up, pull-down and safety factors per 9.3(a)(8) and 9.3(a)(9). These contingency loads are 30% (heating pick-up), 10% (cooling pull-down) and 10% (safety) respectively. The resulting coil capacities are given as follows:

$$\text{Heating capacity} = 360{,}000 \times 1.1 \times 1.3 = 514{,}800 \text{ Btu/h}$$

$$\text{Cooling capacity} = 36 \times 1.1 \times 1.1 = 43.56 \text{ tons}$$

Note that pick-up and pull-down loads are only allowed on systems which are setback, setup or shutoff.

Example 6-I Selecting Design Airflow for the Model

Q

A simulation tool has sized the airflow for a zone at 1.1 cfm/ft^2 and used that value in the calculating the DECOS. The designer plans to use 20% more airflow as a safety factor and to handle the pick-up load. Is the calculated DECOS still acceptable?

A

No. If the installed airflow is to be 1.1 cfm/ft^2 × 1.2 or 1.32 cfm/ft^2, the model must be re-run with this installed value.

Example 6-J Control Schedules – Optimal-Start Feature

Q

The designer of an office building plans to use an optimum-start controller to determine when the fans come on each morning. The fan profiles specified for use with a reference office building call for the fans to start at a fixed time each day. Must the same profiles be used for both the reference building and the proposed design?

A

No. The prototype building shall use the "default" fan profiles. However, since optimum start is a specific energy conservation feature of the proposed design, an optimum-start algorithm would be used to determine fan start time in the proposed design model. In all other ways the fan scheduling of the two models will be the same.

Service Water Heating

This set of modeling rules apply to the service water heating system for both the proposed building and the budget building.

	Proposed Design	*Budget Design*
Service Water Heating Electric	Model the water heating system as designed and shown on the plans and specifications.	Model a storage electric water heater with an energy factor meeting the minimum requirements of Table 11-1 of the Code
Service Water Heating Gas	Model the water heating system as designed and shown on the plans and specifications.	Model a storage gas water heater with an energy factor meeting the minimum requirements of Table 11-1 of the Code
Hot Water Consumption	Use anticipated consumption for the proposed building or take consumption values from Table 13-3 of the Code for the appropriate occupancy type (the values in Table 13-3 are mandatory for multi-family buildings). The consumption figures from Table 13-3 are maximum hourly values and must be adjusted by the schedules in Table 13-5.	Same as the proposed design.
Hot Water Consumption Schedule	Use anticipated hot water consumption schedule or use a schedule from Table 13-5 for the most similar occupancy.	Same as the proposed design.

Table 6-A Default Occupant Receptacle and Water Heating Load Densities

Building Type	Occupant Density (ft^2/person)	Receptacle Power Density (W/ft^2)	Service Hot Water (Btu/h-person)
Assembly	50	0.25	215
Health/Institutional	200	1.00	135
Hotel/Motel	250	0.25	1,110
Light Manufacturing	750	0.20	225
Office	275	0.75	175
Restaurant	100	0.10	390
Retail	300	0.25	135
School	75	0.50	215
Warehouse	15,000	0.10	225

Notes: Heat generation per occupant is 230 Btu/h sensible and 190 Btu/h latent for all building types. The receptacle and service hot water loads given do not include process loads. Load values from this table are to be multiplied by the schedule multipliers of Table 13-5. Multi-family high-rise buildings have special requirements see Table 13-5.

Example 6-K Sizing Service Water Heating Systems

Q

What peak hot water energy usage is to be assumed for the prototype of a 9,000 ft^2 cafeteria?

A

From Table 6-A, the design service hot water quantity for a restaurant is 390 Btu/h-person. From Table 6-A, the design occupancy for a restaurant is 100 ft^2/person. Therefore, the peak hot water energy usage is:

Total peak = (390 Btu/h-person × 9,000 ft^2) / (100 ft^2/person) = 35,100 Btu/h

Other Detailed Input Requirements

Although Article 13 addresses most of the building characteristics to be used in the simulation of the reference building, several other characteristics that will be needed for the model are specifically not covered. Some of those additional input requirements are:

- Percent of heat from lights to return plenum
- Energy usage in transport systems such as elevators and escalators
- Building mass for budget models

In the absence of specific direction, follow this rule: the values used for the budget building shall be the same as the values used for the proposed design. However, the designer may select a more efficient component for the proposed design that carries a higher than conventional price. In this case, one may model the budget building with the conventional component and the proposed design with the more efficient one. Two examples of such features are modulating boiler burner controls and heat extraction light fixtures.

Building thermal mass is a special case. Budget buildings are to be modeled as "light weight" construction, except for walls, which should be modeled as the same construction type (mass) as the proposed design. Proposed buildings are to be modeled with design constructions.

Building transport systems are another special case: they may be omitted from both models altogether. If they are included in the models, the same assumptions shall be used for the budget and proposed building models unless the designer can demonstrate that the difference is due to an energy conserving feature in the proposed design.

As previously mentioned in the section on lighting, exterior and site lighting should either be omitted from both models or modeled the same in both models. Tradeoffs from energy efficient features of exterior and site lighting are *not* allowed.

Example 6-L Use of Non-Specified Input for Reference Building

Q

The designer of an office building has selected recessed heat extraction light fixtures which route the return air through the fixtures to minimize the amount of heat gain into the space from the lights. This will lower the amount of supply air required to cool the space, saving fan energy. The manufacturer of these heat extraction fixtures specifies that 60% of the heat from these lights is transferred to the return plenum compared to 30% from a similar fixture without the heat extraction feature. Must the same values be used for the proposed and reference buildings?

A

No. Since the selected fixture is a specific energy conservation feature, the proposed and reference buildings would be modeled differently: the proposed building would be modeled with the "heat extraction fixtures" (40% light heat to space, 60% light heat to the return plenum); while the reference building would use the typical value (70% light heat to space, 30% light heat to the return plenum).

Speculative Buildings

Speculative buildings may use Article 13 to show compliance. The Code defines a speculative building as "*...a building for which the envelope is designed, constructed, or both, prior to the design of the lighting, HVAC systems, or both. A speculative building differs from a shell building in that the intended occupancy is known for the speculative building.*" Shell buildings may not show compliance through Article 13.

Speculative buildings have special rules pertaining to the lighting and HVAC systems and equipment. These requirements include special documentation of the systems assumed in the proposed building model which will become the basis for future compliance of tenant buildout designs.

Lighting

The budget building lighting allowance shall be based on Section 6.4 as previously described. The proposed building design can be based on *an assumed adjusted lighting allowance for future lighting improvements.* The lighting density used in the proposed design model for calculating the DECOS limits lighting design for future tenant spaces. Two required sets of documentation are used to evaluate the lighting compliance of future tenant spaces:

1. The assumed ALP of the undeveloped tenant spaces that was used in the proposed building model. This is the value (W/ft^2) of all lighting that was not part of the speculative building design. This value can be used by future tenants complying with the prescriptive method of Section 6.4 and *takes precedence over the values in Table 6-5 for these tenants.*

2. A required lighting adjustment (RLA) that can be used by future tenants complying with the system performance method of Section 6.5. This number is the difference on a building wide basis of the adjusted lighting power assumed for the proposed design minus the adjusted lighting power for the budget building. A positive number indicates that the proposed lighting system will have a higher connected lighting power than the budgets from Table 6-5. A negative number indicates that the future lighting will be energy efficient and exceed the requirements of Section 6.4.

If the RLA is a negative number, the designer must also develop a complete lighting design for a representative tenant space to demonstrate that

Example 6-M – Required Lighting Documentation – Speculative Building

Q

A speculative retail building has three undeveloped retail spaces and developed common areas as detailed in the table below. The designer wants to provide 3.0 W/ft^2 for lighting in the future tenant spaces. What documentation is required to show compliance through Article 13?

A

The ULPA for the prototype building from Table 6-5 is 2.83 W/ft^2. As demonstrated in the table below, the ALP for the model of the proposed building is 2.85 W/ft^2.

The ALP for the tenant spaces is 3.0 W/ft^2. This value can be used by the tenants for compliance using the prescriptive approach of Section 6.4.

The RLA for the tenant spaces is 0.02 W/ft^2. It is given by:

$$RLA = ALP_{proposed} - ULPA_{prototype} = 2.85\text{-}2.83 = 0.02\ W/ft^2$$

As the RLA is a positive number, no tenant lighting plan is required. The RLA and the ALP for the tenant spaces are the only documentation that is required.

Note that in addition to this documentation, the proposed design must still demonstrate compliance through the modeling procedures of Article 13. The lighting for the budget building will be 2.83 W/ft^2, and 2.85 W/ft^2 for the proposed design

		Lighting Designed		Lighting Assumed	
Area	GLA (ft^2)	Total Power (W)	Power Density (W/ft^2)	Total Power (W)	Power Density (W/ft^2)
Common space	1,000	1,000	1.00	1,000	1.00
Retail space 1	3,500	N/A	N/A	10,500	3.00
Retail space 2	3,500	N/A	N/A	10,500	3.00
Retail space 3	5,000	N/A	N/A	15,000	3.00
Entire building	13,000	N/A	N/A	37,000	2.85

Example 6-N– Tenant Lighting Compliance – Speculative Building

Q

A tenant is submitting plans for development of one of the spaces in the building in the previous example. What is the lighting power allowance?

A

If the tenant chooses to demonstrate compliance using the prescriptive method, the ILPA is simply 3.0 W/ft^2 for the entire space.

If the tenant chooses to demonstrate compliance using the system performance method, a detailed area-by-area calculation shall be done following the methodology of Section 6.5 described above. The final ILPA developed for the space can be increased by 0.02 W/ft^2. (This increased allowance is not an error. The entire building has demonstrated compliance through Article 13 while assuming these lighting power densities which exceed the prescriptive and system performance requirements).

acceptable lighting can be provided within the power limits set by the assumed adjusted lighting power.

Examples 6-M and 6-N illustrate these calculations.

It is important to bear in mind that the lighting of the speculative building is allowed to exceed the budgets of either Section 6.4 or Section 6.5 as long as the entire building can meet its energy budget. These adjusted interior lighting budgets are recorded so that future tenants may use this energy credit in their lighting system design.

HVAC Systems and Equipment

When the HVAC systems and equipment of a speculative building are not completely designed, the DECOS of the proposed design must be calculated with assumed systems and equipment. These must then be described in the documentation submitted with the plans so that future completion designs can be verified as being equal to, or better than, the assumptions used in calculating the DECOS. This documentation shall include system type, heating and cooling sources, equipment sizes, equipment efficiencies and description of the controls.

Choosing the Simulation Tool

The Code recommends the use of an hour-by-hour, full-year (8,760 hour), multiple-zone program for simulating the performance of both the proposed and budget buildings. Other types of simulation tools may be used that approximate the dynamics of the hourly energy programs and that can be shown to produce equivalent results for the type of building and HVAC systems under consideration. However, the simulation must have the capability of converting calculated energy demand and consumption into utility costs using the actual utility rate schedules (rather than average cost of electricity or gas).

Some illustrations of where an hour-by-hour, full-year type of program would be required are:

- When the relevant features of the proposed design that are intended to reduce energy consumption require time-of-day interactions between weather, loads and operating criteria. Examples include: night ventilation and/or building thermal storage; chilled water or ice storage; heat recovery; daylighting; and water economizer cooling.
- When the appropriate utility rates are time-of-day sensitive, and the proposed design uses time-of-day load shifting between different types of mechanical plant components.

Another distinguishing feature among simulation programs is their sophistication in modeling HVAC systems and plant equipment. There are basically three levels of complexity employed:

- Constant efficiency models
- Models with simple part-load efficiency adjustment
- Models with complex part-load efficiency adjustment

Programs in the first category simply calculate hourly equipment input power requirements at part load by applying the full-load efficiency to the load at any given hour. These programs should be avoided for all but constant load applications (such as described in Example 6-O). They neglect cycling effects, and the change of equipment efficiencies and capacities due to varying environmental conditions.

Example 6-O– Applying a Simplified Energy Analysis Program

Q

Would a simplified energy analysis program be acceptable for calculating the ECB and DECOS of a laboratory using a conventional cooling system and having continuous operation?

A

Yes, because of the continuous operation and the relatively constant internal loads, it should be possible to estimate the annual energy consumption and cost without the dynamics of a detailed hourly simulation program.

Programs with simple part-load efficiency adjustments use a profile of percent rated input power versus percent rated load. At each hour these programs calculate input power to each piece of equipment as follows:

- Calculate the present load on a piece of equipment
- Calculate the ratio of that load to the full-load ratio of the equipment
- Look up the corresponding percent rated input power from the equipment part-load profile
- Calculate the hourly rated input power by multiplying the percent rated input power by the full-load input rating

These programs are far more accurate than the constant efficiency models, but still lack accurate compensation for environmental variables.

The most sophisticated programs incorporate a number of profiles for each and every piece of equipment. For variable flow fans this might be as simple as a single profile of percent rated input power versus percent rated airflow. For more complex equipment such as a cooling tower, the program considers such variables as the wet-bulb temperature, the approach (difference between the condenser water supply temperature and the wet-bulb temperature) and the range (difference between the condenser water entering and leaving temperatures). Each of these variables is used to adjust both the hourly capacity of the tower and the hourly operation (one fan, two fans, no fans). For all but the simplest systems, programs of this category must be used to obtain accurate results. Default curves for common equipment are provided in Appendix E, "Default Equipment Performance Curves".

In evaluating simulation tools, it is advisable to obtain one which permits the user to incorporate their own equipment profiles. This is particularly helpful in the evaluation of relatively new equipment such as direct-fired chillers and screw compressors.

A comprehensive listing of available energy analysis programs can be found in Larry Degelman and Guillermo Andrade, *A Bibliography of Available Computer Programs in the Area of Heating, Ventilation, Air Conditioning and Refrigeration*, ASHRAE, 1986. The entries contain a brief description of the program's capabilities. In some cases these descriptions are sufficient to permit the potential user to decide whether the capability of the program meets the requirements of the planned application. Questions regarding the program's ability to model the building on an hour-by-hour, full-year basis should be addressed to the program's author or distributor.

Glossary

Bin Weather Data	a data file which shows the average number of hours that the ambient dry-bulb temperature falls within various 5 degree bands for a given location. The count of hours is usually shown by month, and frequently in eight-hour blocks (first, middle and last eight hours of the day) within each month. Bin data for Barbers Point is listed in the U.S. military services Engineering Weather Data Manual (AFM 88-29, or TM 5-785, or NAVFAC P-89) and in "Climatic Data for Region X Arizona, California, Hawaii, Nevada", Golden Gate and Southern California Chapters, ASHRAE, Fifth Edition, May 1982. ASHRAE also has bin data in PC disk format available for a large number of cities.
Budget Building	a generic term which represents the reference building.
DECON	(Design Energy Consumption) - the calculated monthly demand and energy consumption of each energy form for the proposed design building.
DECOS	(Design Energy Cost) - the calculated total annual cost of all energy forms for the proposed design building.
Default	a design value or a schedule of time-varying values to be used in the model of the proposed and reference buildings unless the designer can show that a different value is more reasonable for the specific building being modeled. When default values are not used, the same alternate values must be used in both the reference and proposed buildings unless the change is the result of a specific energy conservation feature being used in the proposed design building.
Demand Charges	one or more blocks of cost per kW of monthly demand for the local utility rate applied to the proposed design and reference buildings. Most commercial electric utility rates will have demand charges, and some natural gas utility rates may have demand charges.
ECB (Energy Cost Budget)	the calculated annual cost of energy for the reference building, which then represents the upper limit of annual energy cost of the proposed design.
Footprint	(Form) - the shape of the first floor of a building.
Fuel Adjustment Charges	many utility rates (both electric and gas) are based on a specified fixed cost of purchasing the fuel to be used or delivered, with a provision that the rate will be adjusted each month to account for the difference between the actual cost of purchasing the fuel that month and the assumed cost that was built into the rate base. The adjustment may be positive or negative.
NCDC (National Climatic Data Center)	the primary source of hourly weather data for all U.S. (and many non-U.S.) weather stations. The address is: NCDC, Federal Building, Asheville, NC, 28801-2696.

Orientation	the facing direction of the exterior walls of a building, usually expressed as the facing directions of the longer sides of the building (such as long sides face east/west).
Prescribed	a design value or system characteristic that is to be used without variation in the model of the reference building. In some instances a specific characteristic may be prescribed for the proposed design building.
Proposed Design	the "as designed" building being submitted for compliance under the provisions of Article 13.
Rate Blocks	the steps of cost per kWh or per therm of monthly consumption for the building. The size of the step (block) may be incremental (such as the first 1,000 kWh, the next 2,000 kWh, etc.), or it may be based on demand (such as the first 100 times demand, the next 200 times demand, etc.). Most electric utility rates and natural gas rates have multiple rate blocks, and most have decreasing unit cost with increased consumption. Single step rates are more common among natural gas rates than among electric rates.
Redundant Equipment	"spare" or "excess" or "reserve" equipment which will not be used in normal operation. If the designer has a spare chiller as a standby for emergencies, that chiller would not be included in the model. However, if the designer has installed multiple chillers with excess capacity (redundancy) as a safety measure in such a way that the "spare" chiller may be used in normal operation, that "spare" chiller must be included in the model. For instance, two chillers with each sized at 75% of the expected peak load will provide a redundancy of 50%. In this case, however, both chillers would have to be included in the model since both will operate at some time during the year.
Reference Building	a generic building to be used to establish an ECB. The reference building has exactly the same form (footprint and height), orientation and zoning as the proposed design, but otherwise still must meet all of the applicable prescribed (or system performance) criteria of Articles 5 through 12. The energy cost budget (ECB) is calculated with the characteristics of this building.
Schedules	(Profiles) - the hour-by-hour variation in some design load, temperature setting, or operating parameter for various days of the week. A complete set of schedules is provided for the 10 different building classifications.
Shell Building	a building for which the envelope is designed, constructed, or both prior to knowing the occupancy type. (See also speculative building.)
Speculative Building	a building for which the envelope is designed, constructed, or both prior to the design of the lighting, HVAC systems, or both. A speculative building differs from a shell building in that the intended occupancy is known for the speculative building. (See also shell building.)
Surcharges	many localities impose a tax or similar fee on utility bills, usually expressed as a percentage of the total bill for the month.

Time-of-day Brackets	the specific hours of the day and days of the week into which the electric demand and consumption are divided (the brackets) to permit separate demand and/or consumption rates to be applied to each bracket.
TMY	(Typical Meteorological Year) - a set of hour-by-hour weather data based on a procedure developed by Sandia Laboratories. The data is available from the National Climatic Data Center (NCDC) in Asheville, NC for 234 locations.
TRY	(Test Reference Year) - a set of hour-by-hour weather data based on a procedure developed by ASHRAE's TC 4.2. It consists of 12 contiguous months of data which have been identified as having the fewest deviations from normal in the max/min temperatures. NCDC used the procedure to select weather files for 60 U.S. cities. ASHRAE has those files available on mainframe tape reel form, or they can be obtained from NCDC in microcomputer disks. The procedure is no longer used by ASHRAE or NCDC as a means of identifying "typical year" weather data for cities not included in the original 60 selections.
Utility Rate Structure	the combination of all specific elements of the local utility rates (electric, gas, oil, chilled water, steam) which apply to the proposed design building.
WYEC	(Weather Year for Energy Calculations) - a set of hour-by-hour weather data for SI North American locations prepared under the direction of ASHRAE's weather data committee (TC 4.2) to provide a source of "typical" weather data for hourly energy calculation programs. The data consist of composite "typical" months which have been adjusted to remove short term abnormalities. The data are available from ASHRAE only in mainframe tape reels. the new WYECZ data will be available on diskette.

Appendix A Residential Requirements

Overview

The purpose of this document is to show designers and builders of air-conditioned low-rise residential buildings how to comply with the Hawaii Model Energy Code. This information is distilled from the *Hawaii Model Energy Code Application Manual* which describes all the requirements in more detail. A short brochure for non air-conditioned buildings is available.

The code applies to all low-rise residential buildings. Low-rise residential buildings include multifamily units not more than three stories above grade and all single and two family dwellings.

Some of the requirements apply to all buildings, while others only apply to air conditioned dwellings. The roof insulation, natural ventilation and water heating requirements apply to all dwellings. Air conditioned dwellings must shade windows and walls, and water heaters and air conditioners must meet minimum efficiency requirements.

This brochure is only a summary of the requirements. More detailed information is contained in the *Hawaii Model Energy Code Application Manual.*

Figure A-A Summary of Low-Rise Residential Requirements

Air-conditioned buildings only

SEER must be greater than 10.0 for split systems and 9.7 for packaged systems

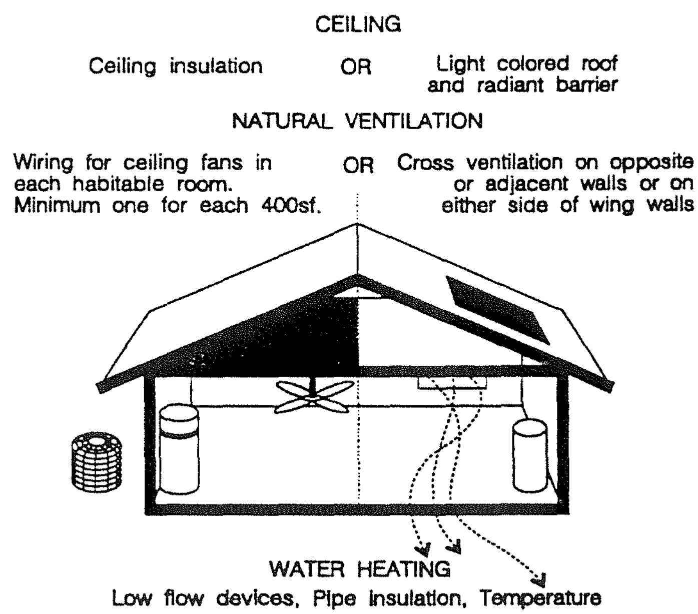
Ducts in unconditioned space must be insulated

Windows must be shaded or tinted. More shading required with larger areas

Doors and windows must be tight fitting

Walls must be insulated or shaded

Skylight size limit



Residential Checklist

All Buildings	Air-conditioned buildings	Requirement	Reference to Code
		Building Envelope	
		Comfort Ventilation	8.3(e)
☐		- cross ventilation or ceiling fans	
☐		- door catches or louvers	
		Air leakage (A/C only)	8.3(e)
	☐	- enclosed spaces	
	☐	- tight doors and windows	
	☐	- joints and cracks sealed	
☐		Roof color, insulation and radiant barrier	8.4(a)
	☐	Wall insulation or shading (A/C only)	8.4(b)
	☐	Window shading (A/C only)	8.4(c)
	☐	Skylights (A/C only)	8.4(d)
		Air Conditioning	
	☐	Minimum air conditioning efficiency	10.3(a), Table 10.1
	☐	Duct insulation	9.3(g)(3)
		Water Heating	
☐		Minimum equipment efficiency	11.3(b)
☐		Hot water conservation	11.3(g), 11.3(i)
☐		Temperature control	11.3(d)
☐		Pipe insulation	11.3(c)
☐		Swimming pools and spas	11.3(j)

Building Envelope

The building envelope requirements cover the roof, walls, windows and skylights as well as comfort ventilation and air leakage. The requirements apply to new dwellings or to additions that increase the floor area of the existing buildings.

The comfort ventilation and roof requirements apply to all dwellings, whether they are air conditioned or not. These requirements are justified for non air-conditioned buildings because they increase comfort and save energy by reducing the possibility that room air conditioners will be installed at a later time. Additional requirements apply to air-conditioned buildings to further reduce cooling loads. These requirements include air leakage, wall insulation, window shading requirements and skylight area limits.

While the requirements are easy to use and can be applied manually, a computer program supports the code and provides additional design flexibility.

All of the building envelope requirements are presented in this section of the brochure.

Comfort Ventilation

The comfort ventilation requirements are intended to reduce or eliminate the need for air conditioning in residential buildings. The requirements apply to all habitable rooms, including bedrooms, living areas and dining rooms. The requirements do not apply to kitchens, hallways, entries, bathrooms or closets. There are two ways to meet the requirements. Adequately sized and positioned windows may be provided or, alternatively, wiring may be installed for ceiling fans. See Figure A-C on the next page.

Figure A-B Overview of the building envelope requirements

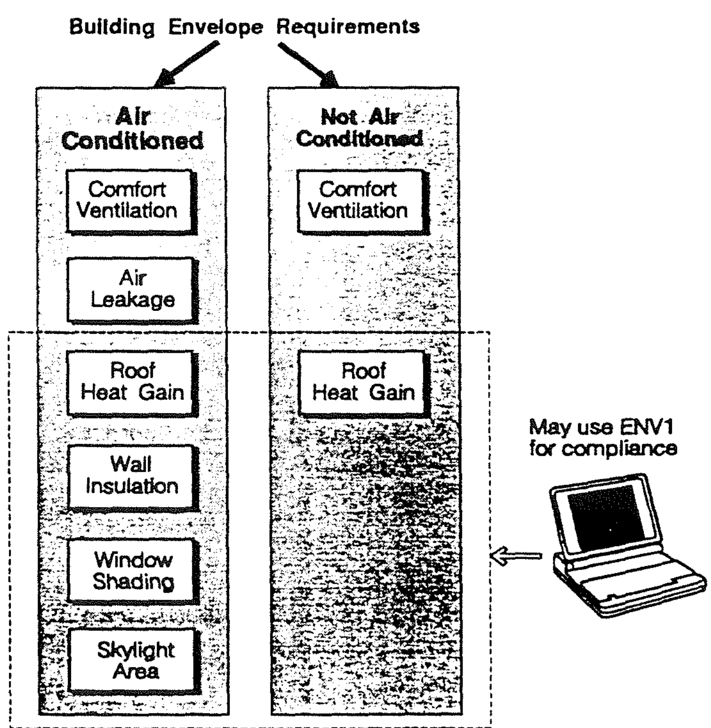
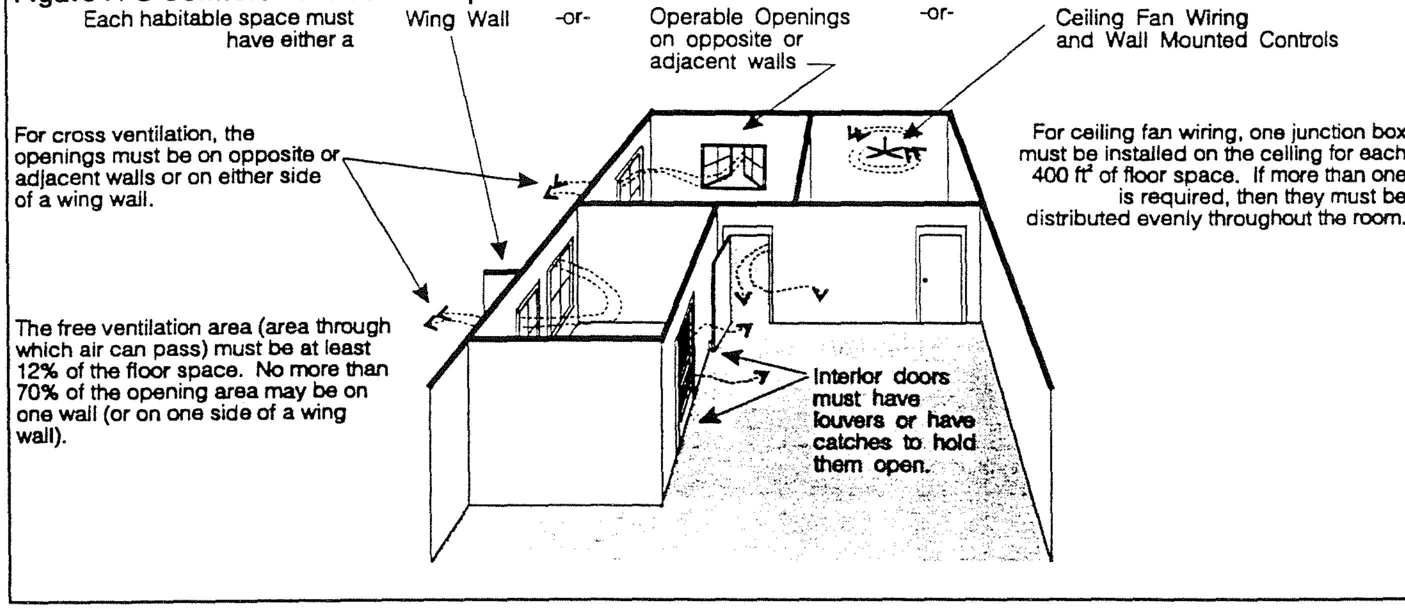


Figure A-C Comfort Ventilation Requirements



Air Leakage (Air Conditioned dwellings only)

The air leakage requirements apply to all air conditioned spaces. They prohibit the cooling of unclosed spaces (except under certain conditions). They also require tightly closing windows and doors, and cracks and holes in the envelope must be sealed. Designers of naturally ventilated dwellings should consider the possibility of future air conditioning and consider meeting the air leakage requirements to avoid potentially costly upgrades.

The requirements are summarized below:

- Air conditioned spaces must be enclosed. The dwelling may have no permanently open walls, windows or doors.
- Doors and windows must be weather-stripped or otherwise tightly sealed to minimize air leakage. Openings such as jalousie windows which cannot be tightly sealed are allowed, but they may not account for more than 2 percent of the exterior wall area.
- Exterior joints, cracks and holes in and between the walls, ceilings and floors which enclose conditioned space must be caulked, gasketed, weather-stripped or otherwise sealed to prevent air leakage.

Roof

Roofs must be either insulated or have a radiant barrier and a light-colored surface. A radiant barrier is a reflective foil sheet that is normally draped at the attic ceiling or stapled between the rafters. Table A-A shows the minimum roof insulation R-value for different roof surface colors with and without a radiant barrier. The figure of merit for color is the surface absorptivity, which is the fraction of solar energy absorbed by the material.

R-values for typical insulation materials are:

- polystyrene foam board, R-5 / inch
- polyisocyanurate foam board, R-7 / inch
- blown-in fiberglass R2-3 / inch
- blown-in cellulose R3-4 / inch
- 3 1/2" fiberglass batt, R-11 to R-15
- 5 1/2" fiberglass batt, R-19 to R-21

Table A-A Minimum Roof R-Value

Roof Surface Color	Absorptivity	Minimum R-Value of Roof Insulation	
		With Radiant Barrier	Without Radiant Barrier
Black or dark gray	0.90	R-3	R-19
Medium Red, Green, Brown, Gray	0.75	R-2	R-15
Yellow, Buff	0.60	R-1	R-11
Light Gray	0.55	R-1	R-8
White (built-up roof)	0.50	R-0	R-7
White (tile, paint, plaster)	0.40	R-0	R-5
White (glazed brick, tile or metal)	0.30	R-0	R-3

Table A-B Typical Insulation Products

R-Value of Insulation	Insulation Thickness (Inch)		
	Fiberglass Batts	Blown-in Insulation	Foam Board
R-19	3½"	5" to 10"	3" to 4"
R-15	3½" to 5½"	4" to 8"	2" to 3"
R-11	3½"	3" to 6"	1½" to 2½"
R-8	2½"	2" to 4"	1" to 1 ½"
R-7	2½"	2" to 4"	1" to 1 ½"
R-5	2"	1½" to 2½"	¾" to 1"
R-3	2"	1" to 2"	½" to ¾"

Table A-C Minimum Overhang Size for Exemption from Wall Insulation Requirement

Wall Height, ft.	Minimum Overhang Size, in.	
	North	East, South or West
7	17	26
8	20	29
9	22	33
10	24	36
11	27	40
12	29	44
13	32	47
14	34	51
15	36	54

Table A-B shows three examples of insulation products and thickness. As density and material type vary, consult with installer or manufacturer for R-values of specific materials.

Walls (Air Conditioned dwellings only)

Walls of air-conditioned dwellings must be either insulated or shaded. With no shading, R-11 insulation will satisfy the requirement. Otherwise, Table A-C gives the overhang size necessary for the wall to remain uninsulated. For example, if the overhang is 8 feet above the bottom of the wall, then the overhang must be at least 29 inches wide on the east, south and west or 20 inches on the north side.

Heavy concrete or brick walls are also exempt from the wall insulation requirement. The *Hawaii Model Energy Code Application Manual* provides more details, but in general, a concrete wall which is at least 4 inches thick or a concrete masonry wall that is at least 6 inches thick (and partially grouted) do not have to be insulated.

Windows (Air Conditioned dwellings only)

Windows in air-conditioned dwellings must be shaded with overhangs or sidefins. Alternatively, special tinted or coated glass may be used to limit solar heat gain into the building. The required amount of shading or tinting depends on the orientation of the windows (north facing windows have separate criteria) and the size of windows relative to the total wall area (the window wall ratio). More shading or tinting is required for large windows and less is needed if they face north. The ability of glass to block solar radiation is given as a shading coefficient (see definition of terms on page A-7).

Figure A-E shows the relationship between window wall ratio, the size of the overhang (projection factor, see definition of terms), and the shading coefficient of the glass. These graphs can be used in a number of ways. If you know the window wall ratio and the size of the overhang, you can determine the maximum shading coefficient or type of glass necessary to meet the code. If you know the window wall ratio and the type of glass, you can determine the minimum overhang size needed to meet the code. In general, if you know any two of the three terms (WWR, SC or PF), you can establish what is required of the remaining term in order to achieve compliance. Figure A-E gives the window criteria for the most common types of glass used in residential buildings: clear, standard tinting, high performance tinting and special laminated or reflective glass. These data are all for a 1/8 in. thickness, except for the special laminated glass which has a total thickness of 1/4 in. The shading coefficient of glass becomes smaller with additional thickness. Chapter 3 of the *Hawaii Model Energy Code Application Manual* gives the general requirement, which can be used with any type of glass. Methods are contained in the manual to take credit for other means of shading such as side fins and exterior sun screens.

Definition of Window Terms

Window Wall Ratio (WWR). The ratio of window area to the total exterior wall area. The larger the WWR, the more shading is required.

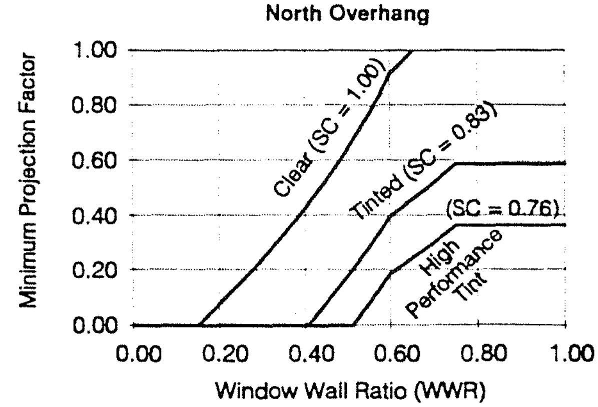
Shading Coefficient (SC). An index of the amount of solar radiation that will pass through a piece of glass. The shading coefficient of 1/8 in. clear glass is 1.0 (by definition) and all other glazing products are rated relative to it. Table A-D gives the shading coefficient for most glazing products used in residential buildings.

Table A-D Typical Shading Coefficients

	Shading Coefficient
Clear	1.00
Bronze	0.85
Gray	0.83
High Performance Tint	0.76
Double Clear	0.91
Double Bronze Outer Lite	0.73
Double Clear with Low-E Coating	0.76
Double Bronze Outer Lite with Low-E Coating	0.59

Projection Factor (PF). The projection factor is an index of the size of an overhang (see Figure A-D). It represents the distance that the overhang projects from the surface of the glass (dimension A) divided by the distance from the window sill to the bottom of the overhang (dimension B).

Figure A-E Maximum Allowed Shading Coefficient with Varying Overhang Size



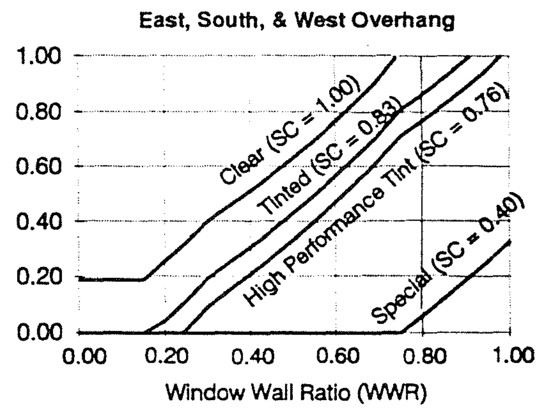
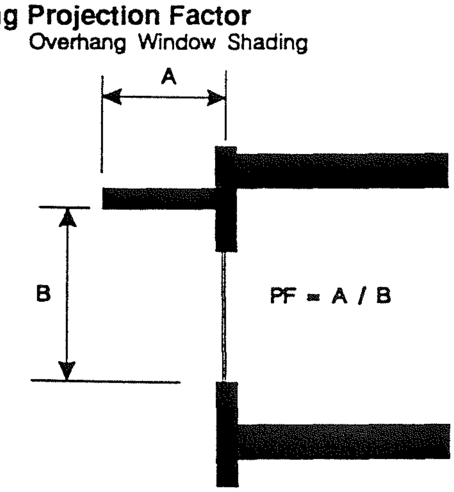


Figure A-D Overhang Projection Factor



Residences that are not air-conditioned or which are located above an elevation of 2,500 ft do not have to meet the window requirements. In addition, dwellings in areas where some heating is required (with more than 800 heating degree days) are exempt. There is also an exemption for small windows up to 2% of the wall area on any orientation. More details on these exemptions are provided in the *Applications Manual.*

Skylights (AC only)

Skylights can save energy by providing daylighting, but they also allow a considerable amount of heat gain to enter the building, thus increasing energy use for air conditioning. To reduce air conditioning loads, the code limits the area of skylights. The maximum area depends on the shading coefficient of the skylight (see definition of terms).

Table A-E shows the maximum allowed skylight area for a range of skylight types. The table is based on a maximum effective aperture limit specified in the code. The maximum skylight areas in Table A-E are horizontal projections, that is, the area is calculated as it would appear on a plan view drawing. Shading coefficients for skylights not listed in Table A-E are available from manufacturers' literature. Non air-conditioned dwellings and those in locations above 2,500 feet or with greater than 800 heating degree days (base 65, see the *Application Manual*) are exempt from the skylight requirements.

Table A-E Maximum Skylight Area, ft^2

Roof Area (ft^2)	Single-Dome Skylights					Double-Dome Skylights				
	Clear	Bronze	High White	Med. White	Low White	Clear	Bronze	High White	Med. White	Low White
	Shading Coefficient					Shading Coefficient				
	0.97	0.53	0.76	0.68	0.45	0.89	0.43	0.72	0.63	0.40
700	18	33	23	26	39	20	41	24	28	44
800	21	38	26	29	44	22	47	28	32	50
900	23	42	30	33	50	25	52	31	36	56
1,000	26	47	33	37	56	28	58	35	40	63
1,200	31	57	39	44	67	34	70	42	48	75
1,400	36	66	46	51	78	39	81	49	56	88
1,600	41	75	53	59	89	45	93	56	63	100
1,800	46	85	59	66	100	51	105	63	71	113
2,000	52	94	66	74	111	56	116	69	79	125
2,500	64	118	82	92	139	70	145	87	99	156
3,000	77	142	99	110	167	84	174	104	119	188
3,500	90	165	115	129	194	98	203	122	139	219
4,000	103	189	132	147	222	112	233	139	159	250

Notes: Roof area and maximum skylight area are listed as horizontal projections. The areas are as they would appear on the drawings in plan view. The shading coefficients are taken from manufacturers' literature for acrylic domed skylights.

ENV1

A computer program called ENV1 supports the standard and may be used to evaluate the design of the building envelope. With this tool, a designer can evaluate the entire exterior wall as a system, taking into account orientation, window area, shading from overhangs or sidefins as well as the thermal properties of the opaque wall. The program is available with the code and will run on any MS-DOS machine. An example of the wall and window screen of the program is shown at the right.

WALLS INPUT

	Wall Surfaces							
	1	2	3	4	5	6	7	8
Orientation	N	n	e	E	s	s	w	w
Wall Area	3000	1300	2000	800	3000	1300	2000	800
Glazing Area	720	1170	480	720	720	1170	480	720
SC	0.5	0.72	0.5	0.72	0.5	0.72	0.5	0.72
VLT	0.25	0.5	0.25	0.5	0.25	0.5	0.25	0.5
PF	0	1	0	1	0	1	0	1
Shade OH,SF,N	n	oh	n	OH	N	oh	n	oh
Wall Type M,O	m	o	m	o	m	o	m	o
Uow	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Ins position	2	2	2	2	2	2	2	2
HC	1	1	1	1	1	1	1	1
Shaded? Y,N	n	y	n	y	n	y	n	y
Air-Con? Y,N	n	n	n	n	n	n	n	n

Press ESC or ENTER to view results

Air Conditioning

These requirements apply to new air conditioning systems of components in new or existing homes. They do not apply to maintenance or repair of existing systems.

Air Conditioner Efficiency

Unitary air conditioners and heat pumps must have a seasonal energy efficiency rating (SEER) of greater than 10.0 for split systems and 9.7 for packaged systems. Split systems are the type where the condenser is located outside, usually on a concrete pad. These minimum efficiency requirements are the same as required by federal law.

Pipe and Duct Insulation

Insulation for ducts inside the building envelope or in unconditioned spaces must be R-3.3 or greater in most cases. If the duct is outside the building, then R-8 insulation is required. Note that ducts outside conditioned space should be well sealed to avoid significant energy loss. Chilled water and refrigerant pipes are required to have 1/2 inch of insulation.

Water Heating

The following requirements apply to all residential water heating systems.

Equipment Efficiency

All water heating equipment must meet the minimum efficiency limits in Table 11-1 of the code. In practice, however, all residential size water heaters must meet these requirements to be sold in the United States, so compliance is not a problem. For commercial size water heaters, refer to the *Application Manual* for information.

Hot Water Conservation

Low-flow shower heads which limit flow to 2.5 gpm must be used. Bathroom faucets must use no greater than 2.0 gpm, and other sinks are limited to 2.5 gpm.

Temperature Control

The water heater thermostat must allow the temperature to be set as low as 110°F.

Pipe Insulation

Pipe insulation is required on the first 8 feet of hot water outlet pipe. Insulation thickness must be at least 1.0 inch. In a circulating system, all the hot water pipes must be insulated.

Swimming Pools, Hot Tubs and Spas

Permanent swimming pools, hot tubs and spas may use only solar or heat pump heating. The heater must have a readily accessible shutoff switch. Pumps must be controlled with time switches so that they may be operated during off-peak periods and so their operation time can be minimized. Pumps for solar heaters do not need time switches, but should be controlled to maintain water temperature.

Appendix B LTGSTD

This appendix includes instructions for using the lighting compliance software LTGSTD. This material is an excerpt from the *User's Guide for ENVSTD™ Program Version 2.1 and LTGSTD™ Program Version 2.1*, Pacific Northwest Laboratory, October 1989. It describes use of the program for compliance with the Department of Energy's federal building standard, but LTGSTD may also be used for the lighting requirements in the Hawaii Model Energy Code. Included here are Section 4 and Appendices C, F and G from the user's guide. Chapter 2 of the *Hawaii Model Energy Code Application Manual* contains an example on the use of LTGSTD.

Note that, like the code, LTGSTD contains two levels of lighting power requirements. In the program they are called the 1989 and 1993 levels, and they are chosen using the F10 key. These two levels are equivalent to the 1991 and 1993 levels in Tables 6-5 and 6-6 of the code.

4.0 LTGSTD™ PROGRAM

Instructions for using the LTGSTD™ program are given in this section. The LTGSTD™ program (from LighTinG STanDards) was designed to help you calculate whether your design complies with the lighting-related requirements detailed in Sections 3.3, 3.4, and 3.5 of the Standards (54 FR 4538-4720). The calculations performed by LTGSTD™ ***exactly duplicate the requirements and compliance calculations contained in Sections 3.3, 3.4, and 3.5 of the Standards.***

The program has four input screens, designated as follows:

- Main
- Space Data
- Controls Data
- Exterior Data.

Sections 4.1 through 4.4 explain what you must do to operate each screen and what you will obtain as a result of those operations.

Two additional aids are provided in this guide to help you use LTGSTD™:

- function key template patterns for your computer keyboard
- sample data files generated by LTGSTD™.

Before you begin to run the LTGSTD™ program, turn to Appendix C. There you will find two keyboard template patterns that may be photocopied and cut out to use on personal computer keyboards with either 84 keys (e.g., IBM PC/XT) or 101 keys (e.g., IBM PC/AT, PS/2). The template will enhance using the LTGSTD™ program because functions have been assigned to specific keys on the keyboard.

The second user aid is in Appendix F, in the form of sample data files for the LTGSTD™ program. The PNL program designers applied the Standards to three buildings and then entered the data from those buildings into the LTGSTD™ program. The resulting three data files, included in Appendix F as hard copy and on the diskette, exemplify how the program works. To review any of these data files using the program, press F1. A listing of the

LTGSTD™ data files in the current default directory will appear, and you will be prompted for a filename. Type the name of the file (**BANK, CHURCH,** or **MEDOFFIC**) and press **Enter**. The LTGSTD™ program will then load the information contained in the file.

Before you enter your own data, please note that LTGSTD™ ***does not calculate power adjustment factors allowed for automatic control devices*** as noted in Section 3.3 of the Standards. You will have to consider these adjustment factors separately.

4.1 MAIN INPUT SCREEN

On the Main input screen, you will typically enter information about the building type, building gross floor area, interior and exterior design lighting power (watts), and a building/project description and date. The LTGSTD™ program automatically calculates the compliance values for Interior Lighting Power Allowance (ILPA) and Exterior Lighting Power Allowance (ELPA). If the design lighting power does not exceed the compliance values, the building design complies. The Main input screen is shown in Figure 4.1. The cursor control keys, special function keys, and data required for this screen are described in the following sections.

4.1.1 Input Requirements

The Main screen has two required entries: building type code(s) and building gross area(s). Two other entries, building description and date, are optional.

BUILDING TYPE If you plan to use the prescriptive compliance path (Section 3.4 of the Standards), enter a character from A to K to designate the appropriate building occupancy. Alternatively, press **F6**, move the cursor to the appropriate building type/area code, and press **Enter**. The prescriptive path is available only for the building type/area codes listed. This option is intended primarily for use with core and shell buildings or during the preliminary design phase. The building type codes are also listed in Table G.1, in Appendix G of this users guide.

```
BUILDING TYPE                    AREA          BUILDING
 NA                               0 ft²           DATE
 NA                               0 ft²           YEAR
 NA                               0 ft²
                                  0 Gross ft²
BUILDING DESIGN
  Interior Lighting Power               0 W            0 W/Gross ft²
  Exterior Lighting Power               0 W
________________________________________________________________________

 PRESCRIPTIVE CRITERIA
   Unit Lighting Power Allowance              NA W/Gross ft²
   Interior Lighting Power Allowance          NA W

 SYSTEM PERFORMANCE CRITERIA
   Unit Power Density                          0 W/Gross ft²
   Interior Lighting Power Allowance           0 W

 EXTERIOR LIGHTING CRITERIA
   Exterior Lighting Power Allowance           0 W

________________________________________________________________________
 F1 Load | F3 Clear     | F5 Space Screen    | F7 Help        | F9 Calc /F10 Year
 F2 Save | F4 Directory | F6 Bldg Type Codes | F8 Ext. Screen | Esc Exit to Dos
```

FIGURE 4.1. Main Input Screen

AREA Enter either the gross area of the entire building or, if significant amounts of different building/occupancy types are present, the gross area of each. The program and the Standards require that different building/occupancy types be at least 10% of the gross building area to be considered. The units are ft^2, and the program accepts values from 0 to 99,999,999.

BUILDING Use this space to identify the project being evaluated. The building name or description is limited to 30 characters.

DATE Use this space to record the date and other information such as the initials of the individual conducting the evaluation. A maximum of 30 characters may be entered.

INTERIOR LIGHTING POWER Enter the total interior lighting power for the building as it has been designed. Include the power required for supplemental and task-related lighting provided by plug-in luminaires as well as permanently installed lighting. The program accepts values from 0 to 999,999,999 W.

EXTERIOR LIGHTING POWER Enter the total exterior lighting power for the building as it has been designed. Include all power used for illumination of roads, grounds, and building exteriors that is energized through the building electrical service. The program accepts values from 0 to 999,999,999 W.

4.1.2 Cursor Control Keys

The keys described below allow you to move the cursor around the Main input screen.

BS Deletes the last character of a column.

← Moves the cursor one column to the left or, if at the left-most column, moves the cursor to the last column of the previous entry.

→ Moves the cursor one column to the right or, if at the right-most column, moves the cursor to the first column of the next entry.

↑ Moves the cursor up one row to the start of the entry above it or, if on the top row, moves the cursor to the bottom row.

↓ Moves the cursor down one row to the start of the entry below or, if on the bottom row, moves the cursor to the top row.

4.1.3 Special Function Keys

Special function keys allow you to calculate compliance, save and recall lighting compliance calculations, and access other features.

F1 Lists all LTGSTD™ data files in the current default directory (all files with .LTG extension). You are then prompted for a filename to load into the LTGSTD™ program.

Any legal DOS filename can be used (up to eight characters in length). The program will read up to 20 characters to allow the use of disk drive and path designations. Enter the disk drive, path, and filename without the .LTG extension.

F2 Saves a LTGSTD™ data file to disk. The files are saved as ASCII files, allowing you to print them later using a text editor or word processor. Enter the disk drive, path, and filename without the .LTG extension.

F3 Clears all data from the Main screen, the Space Data screen, the Controls Data screen and the Exterior Data screen. Initializes all values to zero.

F4 Lists all LTGSTD™ data files in the current default directory with an .LTG extension.

F5 Switches the display from the Main screen to the Space Data screen.

F6 Displays the building type descriptions and codes in a window. From this information you can select the appropriate space type code by pressing **Enter** when the cursor is moved over the desired building type. To return to the Main screen, press **Esc** or the space bar.

F7 Displays a context-sensitive Help message for the information required at the current cursor position. Press any key to return to the Main screen.

F8 Changes the display from the Main screen to the Exterior Data screen.

F9 Calculates the interior lighting power allowance for both the prescriptive and system performance compliance path, and the exterior lighting power allowance. The program also shows if the design values comply with these requirements.

F10 Changes the requirements calculated for the criteria from 1989 values to 1993 values.

Esc Exits from the program.

4.2 SPACE DATA INPUT SCREEN

The cursor control keys, special function keys, and input requirements for the Space Data screen are described in this section. The Space Data screen is shown in Figure 4.2. On this screen, you enter information about the building space--space number designation (optional), space type code, ceiling height, area or dimensions, and number of spaces. The space type description corresponding to the cursor position is displayed at the top of the screen as shown in Figure 4.2. The program automatically calculates the Area Factor (AF), Unit Power Density (UPD), Base Unit Lighting Power Allowance (Pb), Lighting Power Budget (LPB) based on the space data, and Total Lighting Power Budget (TOTAL LPB). It also sums the total building area.

```
SPACE TYPE DESCRIPTION:                                          TOTAL AREA:
SPACE ------------------------------------- NO                                    TOTAL
NO.   TYPE  DIMENSIONS  AREA  CLG HT  SPACES   AF    LPD    Pb    LPB     LPB

Arrows, PgUp, PgDn, and Home Move                 F6 Space Type Codes
Ins Insert Record / Del Delete Record             F7 Help / F8 Main Screen
                                                  F10 Year:
```

FIGURE 4.2. Space Data Input Screen

4.2.1 Input Requirements

You can enter up to 500 spaces for a single building. You need not completely enter one record before you move to a new record. However, incomplete records will not be included in the compliance calculations.

SPACE NO. Enter space numbers to identify individual spaces within the building. Combinations of up to four characters are allowed.

SPACE TYPE Enter an integer from 1 to 131 to designate the appropriate space type code. Alternatively, press **F6**, move the cursor to the appropriate space type code, and press **Enter**. If the space type or activity is not represented in the list, select the code with the most similar space type or activity. Space type codes are also listed in Appendix G of this guide.

DIMENSIONS Enter the length and width of the space, in ft. The program will automatically calculate the floor area. Alternatively, the length and width of the space can be left blank and the area entered directly. The program accepts values from 0 to 999 ft.

AREA Enter the floor area of the space, in ft^2. Alternatively, the length and width of the space, in ft, can be entered under the Dimensions column and the floor area will be calculated automatically. The program accepts values from 0 to 999,999 ft^2.

CLG HT Enter the height of the ceiling, in ft. The program uses the ceiling height to calculate the Area Factor (AF) for each space. The program accepts values from 0 to 500 ft.

Alternatively, enter all other data, then return to the first data line and enter the typical ceiling height. Then press **Ctrl F10**. The program will automatically copy the ceiling height to all lines with data.

NO. SPACES Enter the number of spaces in the building that are like the one described. This value serves as a multiplier, allowing you to enter multiple similar spaces in a single entry. The program accepts values from 0 to 99.

4.2.2 Cursor Control Keys

The keys listed below allow you to move the cursor around the Space Data input screen.

BS Deletes the last character of a column.

← Moves the cursor one column to the left or, if at the leftmost column, moves the cursor to the first column of the same row.

→ Moves the cursor one column to the right or, if at the right-most column, moves the cursor to the last column of the same row.

↑ Moves the cursor up one row in the same column and, if on the top row of the Space Data screen, scrolls the records up one row.

↓ Moves the cursor down one row in the same column and, if on the bottom row of the Space Data screen, scrolls the records down one row.

Ins Inserts a blank record line at the current position of the cursor. This function can be used at any record line of the space data.

Del Deletes a record line at the current position of the cursor. This function can be used to delete any record line of the space data file.

PgUp Moves the cursor up 17 record lines or, if near the beginning of the space input data, advances the cursor to the first record line.

PgDn Moves the cursor down 17 record lines.

Home Moves the cursor to the first record line.

4.2.3 Special Function Keys

The special function keys allow you to move to the other program screens, view and select space type codes, and access Help messages.

F5 Changes the display from the Space Data screen to the Controls Data screen.

F6 Displays the space types and their descriptions in a window when the cursor is in the space type entry column. **F6** allows you to cursor through the types and select one by pressing **Enter**. If no space type is desired, press the space bar or **Esc** to return to the Space Data screen.

When in the space type code window, you can search for a specific space type by pressing F1, entering a character string, and then pressing **Enter**. If you press **F1** and **Enter** again, the program will search for the next occurrence of the character string.

F7 Displays a context-sensitive Help message for the information required at the current cursor position. Press any key to return to the Space Data screen.

F8 Switches the display from the Space Data screen to the Main screen.

F10 Changes the requirements calculated for the criteria from 1989 values to 1993 values.

Ctrl F10 Copies the ceiling height on the line where the cursor is currently located down to all lines where data has been entered.

4.3 CONTROLS DATA INPUT SCREEN

The Standards provide designers with incentives for efficiently controlling electric lighting. The Controls Data screen enables you to record your design's lighting controls and assess their contribution toward compliance with the Standards.

The cursor control keys, special function keys, and input requirements for the Controls Data screen shown in Figure 4.3 are described below. On this screen, you will enter information about the number of tasks or groups of tasks and the type(s) of control(s) installed in the space. The requirements for minimum number of equivalent control points and the credits

SPACE NO.	SPACE DESCRIPTION	SPACE AREA	NO. TASKS	CONTROLS TYPE	CONTROLS NO.	CONTROLS TYPE	CONTROLS NO.	TOTAL EQUIVALENT CONTROL POINTS INSTLD.	TOTAL EQUIVALENT CONTROL POINTS REQD.

Arrows, Pg Up, Pg Dn, and Home Move

F5 Space Screen

F6 Controls Type Codes
F7 Help
F8 Main Screen

FIGURE 4.3. Controls Data Input Screen

for various control types are in Section 3.3.1 of the Standards. The LTGSTD™ program automatically calculates the total control points required for each space, based on the data entered. Space numbers, descriptions, and areas are copied from the Space Data screen.

4.3.1 Input Requirements

Three classes of information are required by the Controls Data input screen:

NO. TASKS Enter the number of separate tasks or groups of tasks in the space. The program uses the number of tasks to calculate the number of control points required for the space.

CONTROL TYPE Enter one of the lighting system control type codes:

- 0 None
- 1 Manual
- 3 Three-Level
- O Occupancy Sensor
- T Timer
- 4 Four-Level
- A Automatic or Continuous Dimming

The program default is 0, no controls.

NO. CONTROLS Enter the number of controls installed in the space for the control type entered in the column to the left. The program accepts values from 0 to 99.

4.3.2 Cursor Control Keys

The following keys allow you to move the cursor around the Controls Data input screen:

BS Deletes the last character of a column.

← Moves the cursor one column to the left or, if at the leftmost column, moves the cursor to the first column of the same row.

→ Moves the cursor one column to the right or, if at the right-most column, moves the cursor to the last column of the same row.

↑ Moves the cursor up one row in the same column and, if on the top row of the Controls Data screen, scrolls the records up one row.

↓ Moves the cursor down one row in the same column and, if on the bottom row of the Controls Data screen, scrolls the records down one row.

PgUp Moves the cursor up 17 record lines or, if near the beginning of the space input data, advances the cursor to the first record line.

PgDn Moves the cursor down 17 record lines.

Home Moves the cursor to the first record line.

4.3.3 Special Function Keys

The special function keys allow you to move to other program screens, view and select controls codes, and access Help messages.

F5 Switches the display from the Controls Data screen to the Space Data screen.

F6 Displays the lighting control types and their descriptions in a window when the cursor is sitting in the controls type columns. You can move the cursor through the controls types and choose one by pressing **Enter**, or you can return to the Controls Data screen by pressing **Esc** or the space bar.

F7 Displays a context-sensitive Help message for the information required at the current cursor position. Press any key to return to the Controls Data screen.

F8 Moves from the Controls Data screen to the Main screen.

4.4 EXTERIOR DATA INPUT SCREEN

The Exterior Data screen, shown in Figure 4.4, lets you enter information about the building's exterior illumination areas in terms of area type and size. After you have input this information, the program then calculates the allowable lighting power densities (in watts) based on Section 3.4 of the Standards.

The input requirements, cursor control keys, and special function keys for the Exterior Data screen are described in the following three sections.

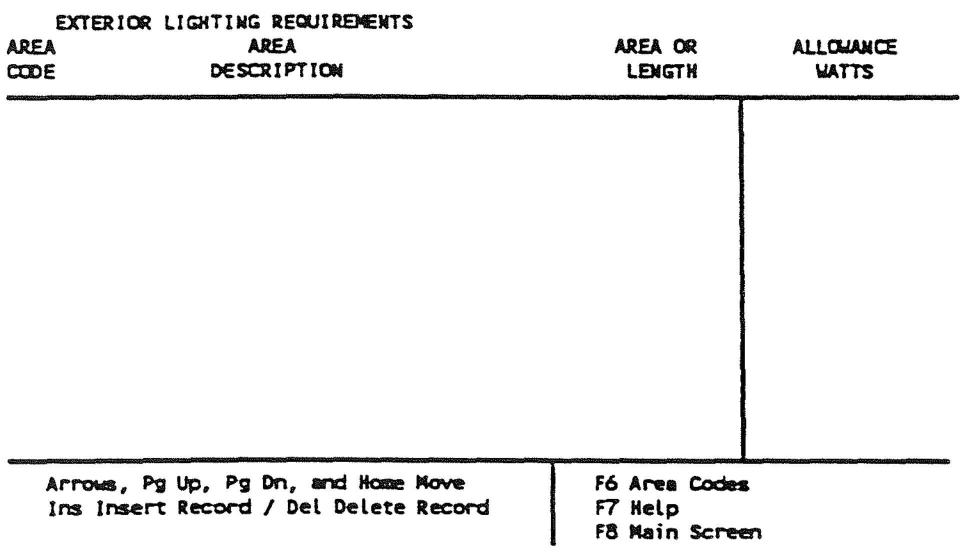


FIGURE 4.4. Exterior Data Input Screen

4.4.1 Input Requirements

Up to 100 exterior illumination areas can be entered for each building. You need not completely enter one record before you move to a new record. However, incomplete records will not be included in the calculations.

AREA CODE Enter an integer from 1 to 13 indicating the appropriate code for each illuminated exterior area. Alternatively, press **F6**, move the cursor to the appropriate area code, and press **Enter**. If the exterior area or activity is not represented by the list, select the code with the most similar area or activity. The exterior area codes are listed in Table G.2.

AREA OR LENGTH Enter either the area or the length corresponding with the illuminated exterior area or surface. For exterior area codes 1, 2 and 6, the values are in linear feet; for other area codes, the values are in square feet. The program accepts values from 0 to 999,999,999. The program uses the area or length in calculating the allowance wattage for each exterior illumination area.

4.4.2 Cursor Control Keys

The following keys allow you to move the cursor around the Exterior Data input screen:

BS Deletes the last character of a column.

← Moves the cursor one column to the left or, if at the leftmost column, moves the cursor to the first column of the same row.

→ Moves the cursor one column to the right or, if at the right-most column, moves the cursor to the last column of the same row.

↑ Moves the cursor up one row in the same column and, if on the top row of the Exterior Data screen, scrolls the records up one row.

↓ Moves the cursor down one row in the same column and, if on the bottom row of the Exterior Data screen, scrolls the records down one row.

Ins Inserts a blank record line at the current position of the cursor. This function can be used at any record line of the exterior data.

Del Deletes a record line at the current position of the cursor. This function can be used at any record line of the exterior data.

PgUp Moves the cursor up 17 record lines or, if near the beginning of the space input data, advances the cursor to the first record line.

PgDn Moves the cursor down 17 record lines.

Home Moves the cursor to the first record line.

4.4.3 Special Function Keys

The special function keys allow you to view and select exterior area codes, get help information for the required data, and change the display from the Exterior Data screen to the Main screen.

F6 Displays a window with exterior area type codes and descriptions. You can move the cursor through the codes and select a code by pressing **Enter**. Pressing any other key will bring you back to the Exterior Data screen.

F7 Displays a context-sensitive Help message for the information required at the current cursor position. Press any key to return to the Controls Data screen.

F8 Changes the display from the Exterior Data screen to the Main screen.

APPENDIX C

FUNCTION KEY TEMPLATES FOR LTGSTD™ PROGRAM

A template that can be photocopied and cut out for use with computer keyboards having 10 function keys is shown in Figure C.1. A template for use with keyboards having 12 function keys is shown in Figure C.2.

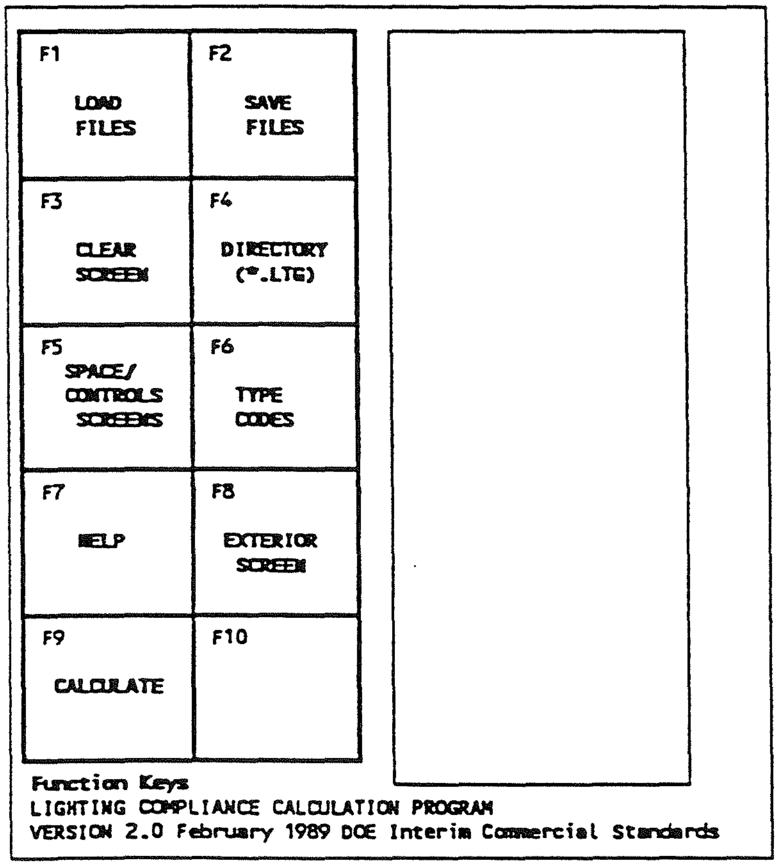


FIGURE C.1. Template for Computer Keyboards with 10 Function Keys

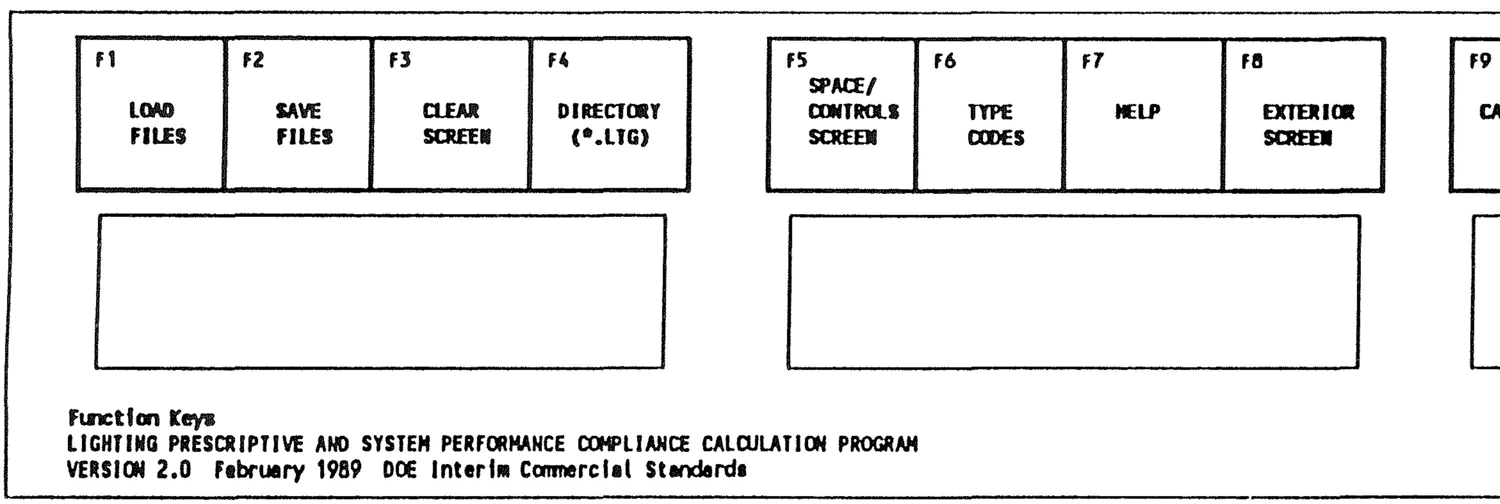


FIGURE C.2. Template for Computer Keyboards with 12 Function Keys

APPENDIX F

EXAMPLE DATA FILES FOR LTGSTD™ PROGRAM

Three files included in this appendix illustrate the calculations possible with the LTGSTD™ program:

- **BANK.LTG** - a single-story, 2,250-ft^2 branch bank building
- **CHURCH.LTG** - a single-story, 12,920-ft^2 church building
- **MEDOFFIC.LTG** - a three-story, 48,664-ft^2 medium office building.

BANK.LTG

LIGHTING PRESCRIPTIVE AND SYSTEM PERFORMANCE COMPLIANCE CALCULATION PROGRAM
VERSION 2.0
U.S. DEPARTMENT OF ENERGY
VOLUNTARY PERFORMANCE STANDARDS FOR NEW COMMERCIAL AND MULTI-FAMILY
HIGH RISE RESIDENTIAL BUILDINGS: MANDATORY FOR FEDERAL BUILDINGS

BUILDING Branch Bank
DATE February 28, 1989
VERSION 1989

BUILDING TYPE		AREA
C Offices		2250 ft²
NA		0 ft²
NA		0 ft²

		2250 Gross ft²
BUILDING DESIGN		
Interior Lighting Power	4874 W	2.166 W/Gross ft²
Exterior Lighting Power	200 W	

PRESCRIPTIVE CRITERIA
Unit Lighting Power Allowance 1.810 W/Gross ft²
Interior Lighting Power Allowance 4073 W

SYSTEM PERFORMANCE CRITERIA
Unit Power Density 2.167 W/Gross ft²
Interior Lighting Power Allowance 4875 W

EXTERIOR LIGHTING CRITERIA
Exterior Lighting Power Allowance 221 W

PASSES

SPACE NO.	SPACE TYPE	SPACE DESCRIPTION	SPACE DIMENSIONS	AREA	CLG HT	NO. SPACES	NO. TASKS	CONTROL TYPE	CONTROL NO.	CONTROL TYPE	CONTROL PTS. NO.	CONTROL PTS. INST.	CONTROL PTS. REQD.	AF	UPD	Pb	LPB	TOTAL LPB
1101	30	Drafting		48	10.0	1	1	0	0	0	0	0	2	1.80	1.00	1.80	86	86
1102	7	Leisure Dini		109	10.0	1	1	0	0	0	0	0	2	1.76	2.50	4.40	479	479
1103	9	Kitchen		176	10.0	1	2	0	0	0	0	0	2	1.52	1.40	2.13	375	375
1104	13	Toilet and W		45	10.0	1	1	0	0	0	0	0	2	1.80	0.80	1.44	65	65
1105	2	Corridor		60	10.0	1	1	0	0	0	0	0	2	1.00	0.80	0.80	48	48
1106	13	Toilet and W		60	10.0	1	1	0	0	0	0	0	2	1.80	0.80	1.44	86	86
1107	35	Conference/M		160	10.0	1	1	0	0	0	0	0	2	1.56	1.80	2.81	450	450
1108	17	Audio Visual		198	10.0	1	3	0	0	0	0	0	2	1.48	1.80	2.66	527	527
1110	44	Inactive Sto		99	10.0	1	1	0	0	0	0	0	2	1.80	0.30	0.54	53	53
1111	44	Inactive Sto		15	10.0	1	1	0	0	0	0	0	2	1.80	0.30	0.54	8	8
1112	44	Inactive Sto		15	10.0	1	1	0	0	0	0	0	2	1.80	0.30	0.54	8	8
1113	17	Audio Visual		80	10.0	1	1	0	0	0	0	0	2	1.55	1.80	2.79	223	223
1114	54	Banking Acti		240	10.0	1	6	0	0	0	0	0	2	1.41	2.80	3.95	949	949
1115	44	Inactive Sto		52	10.0	1	1	0	0	0	0	0	2	1.80	0.30	0.54	28	28
1116	17	Audio Visual		680	10.0	1	10	0	0	0	0	0	3	1.18	1.80	2.13	1446	1446

EXTERIOR LIGHTING REQUIREMENTS

AREA CODE	AREA DESCRIPTION	AREA OR LENGTH	ALLOWANCE WATTS
4	Entrance (with canopy) Light Traffic	24.00 ft²	96.00

DATE February 28, 1989
VERSION 1989

BUILDING TYPE	AREA
NA	12920 ft²
NA	0 ft²
NA	0 ft²

	12920 Gross ft²

BUILDING DESIGN

Interior Lighting Power	25881 W	2.003 W/Gross ft²
Exterior Lighting Power	4000 W	

PRESCRIPTIVE CRITERIA

Unit Lighting Power Allowance	NA W/Gross ft²
Interior Lighting Power Allowance	NA W

SYSTEM PERFORMANCE CRITERIA

Unit Power Density	2.228 W/Gross ft²
Interior Lighting Power Allowance	28792 W

EXTERIOR LIGHTING CRITERIA

Exterior Lighting Power Allowance	4325 W

PASSES

SPACE NO.	TYPE	DESCRIPTION	SPACE DIMENSIONS	AREA	CLG HT	NO. SPACES	NO. TASKS	TYPE	CONTROL NO.	CONTROL TYPE	NO.	CONTROL PTS. INST.	REQD.	AF	UPD	Pb	LPB	TOTAL LPB
1001	3	Classroom/Le		528	8.0	1	1	0	0	0	0	0	2	1.13	2.00	2.26	1195	1195
1002	3	Classroom/Le		80	8.0	1	1	0	0	0	0	0	2	1.60	2.00	3.19	255	255
1003	3	Classroom/Le		80	8.0	1	1	0	0	0	0	0	2	1.60	2.00	3.19	255	255
1004	3	Classroom/Le		216	8.0	1	1	0	0	0	0	0	2	1.28	2.00	2.55	552	552
1005	84	Lobby		49	8.0	1	1	0	0	0	0	0	2	1.80	1.90	3.42	168	168
1006	3	Classroom/Le		83	8.0	1	1	0	0	0	0	0	2	1.58	2.00	3.16	262	262
1007	3	Classroom/Le		96	8.0	1	1	0	0	0	0	0	2	1.52	2.00	3.03	291	291
1008	3	Classroom/Le		80	8.0	1	1	0	0	0	0	0	2	1.60	2.00	3.19	255	255
1009	3	Classroom/Le		80	8.0	1	1	0	0	0	0	0	2	1.60	2.00	3.19	255	255
1010	3	Classroom/Le		96	8.0	1	1	0	0	0	0	0	2	1.52	2.00	3.03	291	291
1011	3	Classroom/Le		240	8.0	1	1	0	0	0	0	0	2	1.25	2.00	2.51	602	602
1012	3	Classroom/Le		630	8.0	1	1	0	0	0	0	0	2	1.11	2.00	2.22	1400	1400
1013	2	Corridor		135	8.0	1	1	0	0	0	0	0	2	1.00	0.80	0.80	108	108
1014	13	Toilet and W		155	8.0	1	1	0	0	0	0	0	2	1.36	0.80	1.09	168	168
1015	2	Corridor		68	8.0	1	1	0	0	0	0	0	2	1.00	0.80	0.80	54	54
1016	13	Toilet and W		56	8.0	1	1	0	0	0	0	0	2	1.79	0.80	1.43	80	80
1017	45	Bulky Active		28	8.0	1	1	0	0	0	0	0	2	1.80	0.30	0.54	15	15
1018	11	Active Traff		44	8.0	1	1	0	0	0	0	0	2	1.80	0.60	1.08	48	48
1019	2	Corridor		354	8.0	1	1	0	0	0	0	0	2	1.00	0.80	0.80	283	283
1020	44	Inactive Sto		32	8.0	1	1	0	0	0	0	0	2	1.80	0.30	0.54	17	17
1021	84	Lobby		336	8.0	1	1	0	0	0	0	0	2	1.19	1.90	2.27	762	762
1022	2	Corridor		745	8.0	1	1	0	0	0	0	0	2	1.00	0.80	0.80	596	596
1023	46	Fine Active		28	8.0	1	1	0	0	0	0	0	2	1.80	1.00	1.80	50	50
1123	44	Inactive Sto		32	8.0	1	1	0	0	0	0	0	2	1.80	0.30	0.54	17	17
1024	3	Classroom/Le		96	8.0	1	1	0	0	0	0	0	2	1.52	2.00	3.03	291	291
1025	3	Classroom/Le		80	8.0	1	1	0	0	0	0	0	2	1.60	2.00	3.19	255	255
1026	3	Classroom/Le		128	8.0	1	1	0	0	0	0	0	2	1.41	2.00	2.83	362	362
1027	17	Audio Visual		132	8.0	1	1	0	0	0	0	0	2	1.40	1.80	2.53	334	334
1028	17	Audio Visual		136	8.0	1	1	0	0	0	0	0	2	1.40	1.80	2.51	342	342
1029	30	Drafting		77	8.0	1	1	0	0	0	0	0	2	1.61	1.00	1.61	124	124
1030	17	Audio Visual		128	8.0	1	1	0	0	0	0	0	2	1.41	1.80	2.55	326	326
1031	17	Audio Visual		128	8.0	1	1	0	0	0	0	0	2	1.41	1.80	2.55	326	326

1036	3	Classroom/Le	96	8.0	1	1	0	0	0	0	0	2	1.58	2.00	3.16	262	262
1037	44	Inactive Sto	32	8.0	1	1	0	0	0	0	0	2	1.52	2.00	3.03	291	291
1038	2	Corridor	354	8.0	1	1	0	0	0	0	0	2	1.80	0.30	0.54	17	17
1039	3	Classroom/Le	240	8.0	1	1	0	0	0	0	0	2	1.00	0.80	0.80	283	283
1040	48	Unlisted Spa	48	8.0	1	1	0	0	0	0	0	2	1.25	2.00	2.51	602	602
1041	9	Kitchen	156	8.0	1	1	0	0	0	0	0	2	1.80	0.20	0.36	17	17
1042	3	Classroom/Le	502	8.0	1	1	0	0	0	0	0	2	1.36	1.40	1.90	296	296
1043	2	Corridor	135	8.0	1	1	0	0	0	0	0	2	1.14	2.00	2.28	1142	1142
1044	3	Classroom/Le	93	8.0	1	1	0	0	0	0	0	2	1.00	0.80	0.80	108	108
1045	84	Lobby	49	8.0	1	1	0	0	0	0	0	2	1.53	2.00	3.06	285	285
1046	84	Lobby	178	8.0	1	1	0	0	0	0	0	2	1.80	1.90	3.42	168	168
1047	56	Worship/Cong	86	20.0	1	1	0	0	0	0	0	2	1.32	1.90	2.51	447	447
1048	2	Corridor	52	8.0	1	1	0	0	0	0	0	2	1.80	2.30	4.14	356	356
1049	13	Toilet and W	180	8.0	1	1	0	0	0	0	0	2	1.00	0.80	0.80	42	42
1050	46	Fine Active	44	8.0	1	1	0	0	0	0	0	2	1.32	0.80	1.06	190	190
1051	56	Worship/Cong	2847	20.0	1	1	0	0	0	0	0	2	1.80	1.00	1.80	79	79
1052	56	Worship/Cong	1505	20.0	1	1	0	0	0	0	0	5	1.22	2.30	2.82	8019	8019
1053	45	Bulky Active	48	8.0	1	1	0	0	0	0	0	3	1.37	2.30	3.15	4741	4741
1054	44	Inactive Sto	32	8.0	1	1	0	0	0	0	0	2	1.80	0.30	0.54	26	26
										0	0	2	1.80	0.30	0.54	17	17

EXTERIOR LIGHTING REQUIREMENTS

AREA CODE	AREA DESCRIPTION	AREA OR LENGTH		ALLOWANCE WATTS
3	Entrance (with canopy) High Traffic	240.00	ft²	2400.00
1	Exit (with or without canopy)	48.00	ft	1200.00
12	Private parking lots	5000.00	ft²	600.00

BUILDING Medium Office
DATE February 1989
VERSION 1989

BUILDING TYPE	AREA
C Offices	48664 ft²
NA	0 ft²
NA	0 ft²

	48664 Gross ft²

BUILDING DESIGN

Interior Lighting Power	82640 W	1.698 W/Gross ft²
Exterior Lighting Power	7500 W	

PRESCRIPTIVE CRITERIA

Unit Lighting Power Allowance	1.650 W/Gross ft²
Interior Lighting Power Allowance	80296 W

SYSTEM PERFORMANCE CRITERIA

Unit Power Density	1.698 W/Gross ft²
Interior Lighting Power Allowance	82640 W

EXTERIOR LIGHTING CRITERIA

Exterior Lighting Power Allowance	7720 W

PASSES

SPACE NO.	TYPE	DESCRIPTION	SPACE DIMENSIONS	AREA	CLG HT	NO. SPACES	NO. TASKS	CONTROL TYPE	CONTROL NO.	CONTROL TYPE	CONTROL NO.	CONTROL INST.	PTS. REQD.	AF	UPD	Pb	LPB	TOTAL LPB
1001	9	Kitchen		500	8.7	1	1	0	0	0	0	0	2	1.17	1.40	1.64	819	819
1002	45	Bulky Active		84	8.7	1	1	0	0	0	0	0	2	1.69	0.30	0.51	43	43
1003	11	Active Traff		160	8.7	1	1	0	0	0	0	0	2	1.42	0.60	0.85	136	136
1004	47	Material Han		399	8.7	1	1	0	0	0	0	0	2	1.21	1.00	1.21	481	481
1005	38	Mail Room		216	8.7	1	1	0	0	0	0	0	2	1.33	1.80	2.40	518	518
1006	23	Atrium First		848	8.7	1	1	0	0	0	0	0	2	1.00	2.20	2.20	1866	1866
1007	2	Corridor		416	8.7	1	1	0	0	0	0	0	2	1.00	0.80	0.80	333	333
1008	9	Kitchen		522	8.7	1	1	0	0	0	0	0	2	1.16	1.40	1.63	851	851
1009	6	Fast Food/Ca		2030	8.7	1	1	0	0	0	0	0	2	1.03	1.30	1.35	2731	2731
1010	12	Emergency Ex		189	8.7	1	1	0	0	0	0	0	2	1.37	0.40	0.55	104	104
1011	17	Audio Visual		189	8.7	1	1	0	0	0	0	0	2	1.37	1.80	2.47	466	466
1012	45	Bulky Active		294	8.7	1	1	0	0	0	0	0	2	1.26	0.30	0.38	111	111
1013	17	Audio Visual		348	8.7	1	1	0	0	0	0	0	2	1.23	1.80	2.21	770	770
1014	16	Laboratory		400	8.7	1	1	0	0	0	0	0	2	1.20	2.30	2.77	1109	1109
1015	30	Drafting		55	8.7	1	1	0	0	0	0	0	2	1.80	1.00	1.80	99	99
1016	25	Locker Room		162	8.7	1	1	0	0	0	0	0	2	1.00	2.70	2.70	437	437
1017	44	Inactive Sto		55	8.7	1	1	0	0	0	0	0	2	1.80	0.30	0.54	30	30
1018	36	Computer/Off		589	8.7	1	1	0	0	0	0	0	2	1.15	2.10	2.41	1420	1420
1019	2	Corridor		192	8.7	1	1	0	0	0	0	0	2	1.00	0.80	0.80	154	154
1020	9	Kitchen		66	8.7	1	1	0	0	0	0	0	2	1.80	1.40	2.52	166	166
1021	13	Toilet and W		144	8.7	1	1	0	0	0	0	0	2	1.46	0.80	1.16	168	168
1022	13	Toilet and W		177	8.7	1	1	0	0	0	0	0	2	1.39	0.80	1.11	197	197
1023	44	Inactive Sto		60	8.7	1	1	0	0	0	0	0	2	1.80	0.30	0.54	32	32
1024	44	Inactive Sto		20	8.7	1	1	0	0	0	0	0	2	1.80	0.30	0.54	11	11
1025	30	Drafting		40	8.7	1	1	0	0	0	0	0	2	1.80	1.00	1.80	72	72
1026	30	Drafting		40	8.7	1	1	0	0	0	0	0	2	1.80	1.00	1.80	72	72
1027	7	Leisure Dini		30	8.7	1	1	0	0	0	0	0	2	1.80	2.50	4.50	135	135
1028	30	Drafting		40	8.7	1	1	0	0	0	0	0	2	1.80	1.00	1.80	72	72
1029	7	Leisure Dini		42	8.7	1	1	0	0	0	0	0	2	1.80	2.50	4.50	189	189
1030	30	Drafting		24	8.7	1	1	0	0	0	0	0	2	1.80	1.00	1.80	43	43
1031	34	Accounting		84	8.7	1	1	0	0	0	0	0	2	1.69	0.80	1.35	114	114

1035	2	Corridor	216	8.7	1	1	0	0	0	0	0	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1036	3	Classroom/Le	984	8.7	1	1	0	0	0	0	0	2	1.00	0.80	0.80	173	173
1037	44	Inactive Sto	20	8.7	1	1	0	0	0	0	0	2	1.09	2.00	2.18	2146	2146
1038	11	Active Traff	18	8.7	1	1	0	0	0	0	0	2	1.80	0.30	0.54	11	11
1039	7	Leisure Dini	541	8.7	1	1	0	0	0	0	0	2	1.80	0.60	1.08	19	19
1040	45	Bulky Active	64	8.7	1	1	0	0	0	0	0	2	1.16	2.50	2.90	1568	1568
1041	35	Conference/M	1062	8.7	1	1	0	0	0	0	0	2	1.80	0.30	0.54	35	35
1042	16	Laboratory	1085	8.7	1	1	0	0	0	0	0	2	1.08	1.80	1.95	2071	2071
1043	35	Conference/M	240	8.7	1	1	0	0	0	0	0	2	1.08	2.30	2.49	2699	2699
1044	23	Atrium First	280	8.7	1	1	0	0	0	0	0	2	1.31	1.80	2.35	565	565
1045	18	Stack Area	2804	8.7	1	1	0	0	0	0	0	2	1.00	2.20	2.20	616	616
2001	23	Atrium First	280	8.7	2	1	0	0	0	0	0	4	1.02	2.60	2.64	7412	7412
2002	23	Atrium First	168	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	616	1232
2003	11	Active Traff	136	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	739
2004	23	Atrium First	156	8.7	2	1	0	0	0	0	0	2	1.48	0.60	0.89	120	241
2005	23	Atrium First	156	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	343	686
2006	2	Corridor	507	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	343	686
2007	23	Atrium First	230	8.7	2	1	0	0	0	0	0	2	1.00	0.80	0.80	406	811
2008	23	Atrium First	168	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	616	1232
2009	23	Atrium First	168	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	739
2010	23	Atrium First	168	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	739
2011	23	Atrium First	168	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	739
2012	17	Audio Visual	2512	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	739
2013	2	Corridor	60	8.7	2	1	0	0	0	0	0	3	1.02	1.80	1.84	4623	9246
2014	23	Atrium First	165	8.7	2	1	0	0	0	0	0	2	1.00	0.80	0.80	48	96
2015	23	Atrium First	180	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	363	726
2016	35	Conference/M	316	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	396	792
2017	13	Toilet and W	30	8.7	2	1	0	0	0	0	0	2	1.25	1.80	2.25	710	1419
2018	70	Nurse Statio	186	8.7	2	1	0	0	0	0	0	2	1.80	0.80	1.44	43	86
2019	2	Corridor	532	8.7	2	1	0	0	0	0	0	2	1.37	2.10	2.89	537	1073
2020	23	Atrium First	168	8.7	2	1	0	0	0	0	0	2	1.00	0.80	0.80	426	[illegible]
2021	23	Atrium First	168	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	[illegible]
2022	23	Atrium First	252	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	[illegible]
2023	23	Atrium First	168	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	554	[illegible]
2024	23	Atrium First	168	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	[illegible]
2025	23	Atrium First	140	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	739
2026	46	Fine Active	218	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	308	616
2027	34	Accounting	24	8.7	2	1	0	0	0	0	0	2	1.33	1.00	1.33	290	580
2028	2	Corridor	66	8.7	2	1	0	0	0	0	0	2	1.80	0.80	1.44	35	69
2029	23	Atrium First	36	8.7	2	1	0	0	0	0	0	2	1.00	0.80	0.80	53	106
2030	34	Accounting	30	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	79	158
2031	23	Atrium First	162	8.7	2	1	0	0	0	0	0	2	1.80	0.80	1.44	43	86
2032	23	Atrium First	162	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	356	713
2033	2	Corridor	126	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	356	713
2034	23	Atrium First	189	8.7	2	1	0	0	0	0	0	2	1.00	0.80	0.80	101	202
2035	23	Atrium First	150	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	416	832
2036	13	Toilet and W	144	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	330	660
2037	13	Toilet and W	177	8.7	2	1	0	0	0	0	0	2	1.46	0.80	1.16	168	335
2038	44	Inactive Sto	21	8.7	2	1	0	0	0	0	0	2	1.39	0.80	1.11	197	393
2039	34	Accounting	60	8.7	2	1	0	0	0	0	0	2	1.80	0.30	0.54	11	23
2040	30	Drafting	1024	8.7	2	1	0	0	0	0	0	2	1.80	0.80	1.44	86	173
2041	35	Conference/M	86	8.7	2	1	0	0	0	0	0	2	1.09	1.00	1.09	1113	2226
2042	11	Active Traff	144	8.7	2	1	0	0	0	0	0	2	1.68	1.80	3.02	260	520
2043	34	Accounting	35	8.7	2	1	0	0	0	0	0	2	1.46	0.60	0.87	126	251
2044	2	Corridor	232	8.7	2	1	0	0	0	0	0	2	1.80	0.80	1.44	50	101
2045	7	Leisure Dini	30	8.7	2	1	0	0	0	0	0	2	1.00	0.80	0.80	186	371
2046	30	Drafting	24	8.7	2	1	0	0	0	0	0	2	1.80	2.50	4.50	135	270
2047	7	Leisure Dini	42	8.7	2	1	0	0	0	0	0	2	1.80	1.00	1.80	43	86
2048	30	Drafting	24	8.7	2	1	0	0	0	0	0	2	1.80	2.50	4.50	189	378
2049	34	Accounting	168	8.7	2	1	0	0	0	0	0	2	1.80	1.00	1.80	43	86
2050	23	Atrium First	168	8.7	2	1	0	0	0	0	0	2	1.40	0.80	1.12	189	378
													1.00	2.20	2.20	370	739

MEDOFFIC.LTG (contd)

SPACE NO.	TYPE	DESCRIPTION	SPACE DIMENSIONS	AREA	CLG HT	NO. SPACES	NO. TASKS	CONTROL TYPE	CONTROL NO.	CONTROL TYPE	CONTROL NO.	CONTROL PTS. INST.	CONTROL PTS. REQD.	AF	UPD	Pb	LPB	TOTAL LPB
2051	35	Conference/M		224	8.7	2	1	0	0	0	0	0	2	1.32	1.80	2.38	534	1068
2052	23	Atrium First		280	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	616	1232
2053	23	Atrium First		280	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	616	1232
2054	35	Conference/M		280	8.7	2	1	0	0	0	0	0	2	1.27	1.80	2.29	641	1283
2055	23	Atrium First		168	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	739
2056	23	Atrium First		168	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	370	739
2057	23	Atrium First		1324	8.7	2	1	0	0	0	0	0	2	1.00	2.20	2.20	2913	5825

EXTERIOR LIGHTING REQUIREMENTS

AREA CODE	AREA DESCRIPTION	AREA OR LENGTH		ALLOWANCE WATTS
3	Entrance (with canopy) High Traffic	160.00	ft²	1600.00
4	Entrance (with canopy) Light Traffic	80.00	ft²	320.00
1	Exit (with or without canopy)	40.00	ft	1000.00

APPENDIX G

BUILDING TYPE, EXTERIOR AREA, AND SPACE TYPE CODES FOR LTGSTD™ PROGRAM

This appendix shows the building type, exterior area, and space type codes incorporated into the LTGSTD™ program.

Building type codes are based on the list of building occupancies/types in Table 3.4-1 of the Standards. Table G.1 lists the building type codes [with the corresponding unit lighting power allowance (ULPA) values for both 1989 and 1993] for use with the LTGSTD™ program.

The exterior type codes are based on the list of roads, grounds, and other exterior illumination areas in Table 3.4-2 of the Standards. Table G.2 lists the exterior type codes [with their corresponding unit power densities (UPDs)] for use with the LTGSTD™ program.

The space type codes are based on the list of spaces/functions in Table 3.5-1 of the Standards. The UPD values shown for each space type have also been incorporated directly into the program. Table G.3 lists the space type codes for various space functions (with their corresponding UPD values for 1989 and 1993) used with the LTGSTD™ program.

TABLE G.1. Building Type Codes

Type Code	Building Type	Prescriptive Unit Lighting Power Allowance (ULPA), W/ft² for Gross Lighted Area Ranges: 0 to 2,000 ft²	2,001 to 10,000 ft²	10,001 to 25,000 ft²	25,001 to 50,000 ft²	50,001 to 250,000 ft²	>250,000 ft²	Effective Date
A	Fast Food/Cafeteria	1.50	1.38	1.34	1.32	1.31	1.30	1989
		0.92	0.85	0.82	0.81	0.81	0.80	1993
B	Leisure Dining/Bar	2.20	1.91	1.71	1.56	1.46	1.40	1989
		1.60	1.56	1.52	1.48	1.44	1.40	1993
C	Offices	1.90	1.81	1.72	1.65	1.57	1.50	1989
		1.40	1.34	1.27	1.22	1.16	1.11	1993
D	Retail	3.30	3.08	2.83	2.50	2.28	2.10	1989
		2.70	2.52	2.32	2.05	1.87	1.72	1993
E	Mall Concourse	1.60	1.58	1.52	1.46	1.43	1.40	1989
		0.69	0.68	0.65	0.63	0.61	0.60	1993
F	Service Establishment	2.70	2.37	2.08	1.92	1.80	1.70	1989
		2.81	2.03	1.78	1.65	1.54	1.46	1993
G	Garage	0.30	0.28	0.24	0.22	0.21	0.20	1989
		0.25	0.24	0.23	0.22	0.21	0.20	1993
H	Pre/Elementary School	1.80	1.80	1.72	1.65	1.57	1.50	1989
		1.33	1.33	1.27	1.22	1.16	1.11	1993
I	High School	1.90	1.90	1.88	1.83	1.76	1.70	1989
		1.40	1.40	1.39	1.35	1.30	1.26	1993
J	Technical/Voc. School	2.40	2.33	2.17	2.01	1.84	1.70	1989
		1.77	1.72	1.60	1.49	1.36	1.26	1993
K	Warehouse/Storage	0.80	0.66	0.56	0.48	0.43	0.40	1989
		0.60	0.50	0.42	0.36	0.32	0.30	1993

TABLE G.2. Exterior Area Codes

Area Type Code	Area Type	Unit Power Density
1	Exit (with or without canopy)	25 W/Lin. ft of door opening
2	Entrance (without canopy)	30 W/Lin. ft of door opening
3	Entrance (with canopy) High Traffic	10 W/ft^2 of canopied area
4	Entrance (with canopy) Light Traffic	4 W/ft^2 canopied area
5	Entrance (with canopy) Loading Area	0.40 W/ft^2
6	Entrance (with canopy) Loading Door	20 W/Lin. ft of door opening
7	Building Exterior Surface Facade	0.25 W/ft^2 of surface area to be illuminated
8	Storage and non-manufacturing work area	0.20 W/ft^2
9	Other activity areas for casual use	0.10 W/ft^2
10	Private driveway/walkways	0.10 W/ft^2
11	Public driveways/walkways	0.15 W/ft^2
12	Private parking lots	0.12 W/ft^2
13	Public parking lots	0.18 W/ft^2

TABLE G.3. Space Type Codes

Space Type Code	Description	Unit Power Density 1989	Unit Power Density 1993
Auditorium			
1	Auditorium	1.6	1.4
Corridor			
2	Corridor	0.8	0.8
Classroom/Lecture Hall			
3	Classroom/Lecture Hall	2.0	1.0
Electrical/Mechanical Equipment Room			
4	General	0.7	0.7
5	Control Room	1.5	1.5
Food Service			
6	Fast Food/Cafeteria	1.3	0.8
7	Leisure Dining	2.5	1.4
8	Bar/Lounge	2.5	1.3
9	Kitchen	1.4	1.4
Recreation/Lounge			
10	Recreation/Lounge	0.7	0.5
Stair			
11	Active Traffic	0.6	0.6
12	Emergency Exit	0.4	0.4
Toilet and Washroom			
13	Toilet and Washroom	0.8	0.5
Garage			
14	Auto and Pedestrian Circulation	0.3	0.25
15	Parking Area	0.2	0.2
Laboratory			
16	Laboratory	2.3	2.2
Library			
17	Audio Visual	1.1	1.1
18	Stack Area	1.5	1.5
19	Card Filing & Cataloging	1.6	0.8
20	Reading Area	1.9	1.0
Lobby (General)			
21	Reception and Waiting	1.0	0.55
22	Elevator Lobbies	0.8	0.4
Atrium (Multi-Story)			
23	First 3 Floors	0.7	0.4
24	Each Additional Floor	0.2	0.15
Locker Room and Shower			
25	Locker Room and Shower	0.8	0.6
Offices (Partitions > 4.5 ft below ceiling). Enclosed offices, all open plan offices without partitions or with partitions lower than 4.5 ft below the ceiling.			
26	Reading, Typing & Filing	1.8	1.3
27	Drafting	2.6	2.2
28	Accounting	2.1	1.8
Offices (Partitions 3.5-4.5 ft below ceiling). Open plan offices 900 ft^2 or larger with partitions 3.5 to 4.5 ft below the ceiling.			
29	Reading, Typing & Filing	1.9	1.5
30	Drafting	2.9	2.6
31	Accounting	2.4	2.1
Offices (Partitions < 3.5 ft below ceiling). Open plan offices 900 ft^2 or larger with partitions higher than 3.5 ft below the ceiling. Offices less than 900 ft^2 shall use types 26, 27, or 28.			
32	Reading, Typing & Filing	2.2	1.7
33	Drafting	3.4	3.0
34	Accounting	2.7	2.4
Common Activity Areas			
35	Conference/Meeting Room	1.8	1.3
36	Computer/Office Equipment	2.1	2.1
37	Inactive Filing	1.0	1.0
38	Mail Room	1.8	1.8
Shop (Non-Industrial)			
39	Machinery	2.5	2.5
40	Electrical/Electronic	2.5	2.5
41	Painting	1.6	1.6
42	Carpentry	2.3	2.3
43	Welding	1.2	1.2
Storage & Warehouse			
44	Inactive Storage	0.3	0.2
45	Bulky Active Storage	0.3	0.3
46	Fine Active Storage	1.0	0.9
47	Material Handling	1.0	1.0
Unlisted Space			
48	Unlisted Space	0.2	0.2

TABLE G.3. (contd)

Space Type Code	Description	Unit Power Density 1989	Unit Power Density 1993
Airport, Bus & Rail Station			
49	Baggage Area	1.0	0.75
50	Concourse/Main Thruway	0.9	0.45
51	Ticket Counter	2.5	1.3
52	Waiting & Lounge Area	1.2	0.6
Bank			
53	Customer Area	1.1	0.8
54	Banking Activity Area	2.8	2.2
Barber & Beauty Parlor			
55	Barber & Beauty Parlor	2.0	1.6
Church, Synagogue, Chapel			
56	Worship/Congregational	2.5	1.3
57	Preaching & Sermon/Choir	2.7	1.8
Dormitory			
58	Bedroom	1.1	0.6
59	Bedroom with Study	1.4	1.3
60	Study Hall	1.8	0.9
Fire & Police Department			
61	Fire Engine Room	0.7	0.7
62	Jail Cell	0.8	0.4
Hospital/Nursing Home			
63	Corridor	1.3	0.9
64	Dental Suite/Exam/Treatment	1.6	1.4
65	Emergency	2.3	2.0
66	Laboratory	1.9	1.7
67	Lounge/Waiting Room	0.9	0.6
68	Medical Supplies	2.4	2.4
69	Nursery	2.0	1.6
70	Nurse Station	2.1	1.8
71	Occu./Physical Therapy	1.6	1.4
72	Patient Room	1.4	0.9
73	Pharmacy	1.7	1.5
74	Radiology	2.1	1.8
Surgery & O.B. Suites			
75	General Area	2.1	1.8
76	Operating Room	7.0	6.0
77	Recovery	3.0	2.0

Space Type Code	Description	Unit Power Density 1989	Unit Power Density 1993
Hotel/Conference Center			
78	Banquet/Multipurpose Room	2.4	1.4
79	Bathroom/Powder Room	1.2	0.6
80	Guest Room	1.4	0.7
81	Public Area	1.2	0.8
82	Exhibition Hall	2.6	1.3
83	Conference/Meeting	1.8	1.5
84	Lobby	1.9	1.3
85	Reception Desk	2.4	2.4
Laundry			
86	Washing	0.9	0.6
87	Ironing & Sorting	1.3	1.3
Museum & Gallery			
88	General Exhibition	1.9	1.2
89	Inspection/Restoration	3.9	3.0
90	Inactive Artifacts Storage	0.6	0.25
91	Active Artifacts Storage	0.7	0.5
Post Office			
92	Lobby	1.1	0.8
93	Sorting & Mailing	2.1	2.1
Service Station/Auto Repair			
94	Service Station	1.0	0.8
Theater			
95	Performance Arts	1.5	1.1
96	Motion Picture	1.0	0.75
97	Lobby	1.5	1.0
Retail Establishments (Merchandising & Circulation Area) Applicable to all lighting, including accent and display lighting, installed in merchandising and circulation areas.			
98	Type A (Mass Merchandising)	5.6	6.0
99	Type B (Service Retail)	3.2	2.9
100	Type C (Mixed Use Retail)	3.3	2.7
101	Type D (Specialty Shop)	3.1	2.5
102	Type E (Fine Merchandise)	2.8	2.4
103	Type F (Service Establishment)	2.7	2.6
104	Mall Concourse	1.4	0.6

TABLE G.3. (contd)

Space Type Code	Description	Unit Power Density 1989	1993
	Retail Support		
105	Tailoring	2.1	2.1
106	Dressing/Fitting Rooms	1.4	1.1
	All Sports		
107	Seating Area	0.4	0.4
	Badminton		
108	Club	0.5	0.5
109	Tournament	0.8	0.8
	Basketball/Volleyball		
110	Intramural	0.8	0.8
111	College	1.3	1.3
112	Professional	1.9	1.9
	Bowling		
113	Approach Area	0.5	0.5
114	Lanes	1.1	1.1
	Boxing/Wrestling (Platform)		
115	Amateur	2.4	2.4
116	Professional	4.8	4.8
	Gymnasium		
117	General Exercise & Recreation	1.0	1.0
	Handball/Racquetball/Squash		
118	Club	1.3	1.3
119	Tournament	2.6	2.6
	Ice Hockey		
120	Amateur	1.3	1.3
121	College/Professional	2.6	2.6
	Skating Rink		
122	Recreational	0.6	0.6
123	Exhibition/Professional	2.6	2.6
	Swimming		
124	Recreational	0.9	0.9
125	Exhibition	1.5	1.5
126	Underwater	1.0	1.0
	Tennis		
127	Recreational (Class III)	1.3	1.3
128	Club/College (Class II)	1.9	1.9
129	Professional (Class I)	2.6	2.6
	Table Tennis		
130	Club	1.0	1.0
131	Tournament	1.6	1.6

Appendix C ENV1 User's Guide

Overview

ENV1 is a tool for checking compliance with the system performance requirements for walls and windows and the prescriptive requirements for roofs and skylights (see Chapter 3). The program contains two independent parts. In the first, the user describes the proposed building's walls and windows. Then the program compares the cooling load in the proposed building to the cooling load in a reference building. The reference building is one that complies with the prescriptive requirements. In the second part of the program, the designer describes the roof and skylights, and the program checks for compliance with the prescriptive requirements.

How to Install ENV1

To install the program, copy the three files ENV1.EXE, ENV1.ENV and OFFICE.ENV from the floppy disk to a location on your hard drive. The first two files contain the program and the third file is a sample building. If you choose to run the program from the floppy disk, be sure to make a backup copy beforehand.

How to Use ENV1

From the directory where the files ENV1.EXE and ENV1.ENV are located, type *ENV1* to start the program. After the introductory screen appears, press a key corresponding to the type of screen on your computer: *C* for color, *B* for black and white and *M* for monochrome.

The main menu includes seven choices, as shown in Figure C-A. Use the arrow keys to move among the menu items and press Enter or simply press the first letter of the word to select an item from the menu. Each of these choices is described below.

Figure C-A ENV1 Menu Structure

File Project Walls Roof Output Color Quit

Roof: **Input Results Main-Menu**

Walls: **Input Results Main-Menu**

File: **New Open Save Directory List Main-Menu**

File

Allows the user to start a *New* file, *Open* an existing file, to *Save* a file, to change the default *Directory* or to view a *List* of the files in the current directory. These menu choices are described below.

New — Erases the current building data.

Open — Retrieves data from a previously saved file. Current data will be erased and replaced with the new file. Be sure to try to open only files which were created earlier using the save command (or the sample file OFFICE.ENV). Otherwise an error may occur and it will be necessary to restart the program.

Save — Saves the current building data in a file named by the user. The name may be no longer than 8 characters. The program will add the *.ENV extension, so a file named MYHOUSE will be saved as MYHOUSE.ENV.

Directory — Allows the user to enter the directory path to be used by the Open, Save and List commands. For example C:\ENV1. When the program starts, the default directory is the one from which the program was started.

List — Displays a list of the *.ENV files in the current default directory. After viewing the list press any key to return to the file menu.

Main-Menu — Returns to the main menu

Project

Choosing *Project* on the main menu allows the user to enter general information about the building as described below.

Project Name — This is optional, for identification purposes only.

Date — This is also optional. The date should be entered beginning with a letter. For example, Oct 12, 1992.

Location — Enter 1 for Barber's Point, 2 for Hilo, 3 for Honolulu or 4 for Lihue. For other locations choose the most similar climate.

Low-Rise Res.?(Y/N) — Enter "y" or "n". The window requirements are different for low-rise residential buildings (including all single and double unit buildings as well as multi-unit residential buildings with fewer than 3 stories above grade).

Air-Cond.? (Y/N) — Enter "y" if the building is to be air conditioned and "n" if not.

Heating Climate? (Y/N) — If the location of the building is higher than 2,500 ft above sea level or has greater than 800 heating degree days (base 65 °F), then enter "y". Otherwise enter "n". This is relevant only for low-rise residential buildings and allows an exemption from the window shading requirements. See *heating degree days* in the glossary to Chapter 3.

Walls

The choices include *Input*, which allows the user to enter the wall and window data; *Results*, which causes the calculation results to be displayed, telling the designer whether the walls and windows comply; and *Main-Menu*, which returns operation to the main menu.

Input

Figure C-C shows the *Walls* input screen. The user may identify as many as eight wall surfaces. Several walls may be grouped together if they have the same characteristics and they face the same direction. Conversely, a single wall may be entered as 2 or more wall surfaces if it contains more than one glass type, wall type or shading condition. For some buildings eight wall surfaces will not be enough to account for all the different wall and window conditions. In that case, area-weighted averages should be calculated for the characteristics of wall surfaces which represent more than one condition.

Use the arrow keys to move around the screen. Type an entry and press Enter or just move to the next cell with the arrow keys. To erase an entry, press the "Delete" key. To leave this screen, press "Enter" a second time or press "Esc" after the final entry.

The wall and window data entries are described below.

Orientation

Enter "n", "s", "e" or "w" for each wall surface (either capital or lower-case letters). Choose the orientation closest to actual orientation of the wall. Note that a surface that is tilted at less than 60° from horizontal is considered a roof or a skylight and may not be included in this calculation.

Wall Area

Enter the gross wall area in ft^2 or m^2, including windows.

Glazing Area

Enter window area, including frames, in ft^2 or m^2 (use same units as for Wall Area).

SC

Enter the shading coefficient of the window. SC may be a value from 0.0 to 1.0. If more than one window type is included in a single wall surface, then use an area-weighted average SC. If interior or exterior shades are used for credit as described in the code, then enter an adjusted shading coefficient here (note overhangs or sidefins are not included in the determination of SC). See *shading coefficient* in the Chapter 3 glossary for more information.

VLT

Enter the visible light transmission of the glazing. VLT may be a value from 0.0 to 1.0. If interior shades are considered for SC credit, then adjust the VLT entry by the same amount as the SC entry. It is always acceptable to use 0 if the actual VLT is unknown. See *visible light transmittance* in the glossary to Chapter 3.

PF

Enter the projection factor of an overhang or a sidefin shading device (enter 0 for none). For an overhang, PF is equal to the ratio between the projection of the shade from the window surface and the distance from the bottom of the window to the bottom of the overhang. PF may range from 0 to 1.5. A PF of 0 may be used if the projection factor is not known. See *projection factor* in the Chapter 3 glossary for more details.

Shade OH,SF,N

Enter "oh" if the window shade is an overhang or "sf" if it is a sidefin (enter "n" or "0" for no shade). Credit is allowed for only one or the other. If a window is shaded by both an overhang and a sidefin, then the user may try each to see which provides a lower "Proposed" cooling score (see "Results" screen).

Wall Type, M/O

Enter "m" for a metal framed wall or "o" for any other type. This input is necessary because the U-value requirement depends on wall type.

U_{ow}.

Enter the U-value of the exterior wall (Btu/h·ft^2·°F). Typical values range from 0.05 to 0.40. See *U-value* in the Chapter 3 glossary for calculation of U-values.

Ins position

Insulation position relative to the wall's thermal mass. Enter "1" for exterior, "2" for integral and "3" for interior insulation. Insulation position is relevant only if the heat capacity (HC) of the wall is greater than 1.

HC

Enter the heat capacity (HC) of the exterior wall in Btu/ft^2·°F. For typical frame walls, HC = 1.0. Credit for HC greater than 21 is not given for walls. See *heat capacity* in the glossary to Chapter 3 to determine HC for concrete or brick walls.

Shaded? Y/N

Enter "y" if the wall is shaded or "n" if it is not. An opaque wall is considered shaded if it is completely shaded from the sun all year by adjacent buildings, an overhang or a feature of the landscape such as a hill or cliff. In addition, a wall is considered shaded if it is shaded by an overhang with a projection factor no less than 0.2 on north walls or 0.3 on east, south or west walls. See the prescriptive requirements for walls.

Air Con? Y/N

Enter "y" if the wall encloses directly or indirectly air conditioned space; otherwise enter "n" is the space is not air conditioned.

Results

The walls Results screen (Figure C-D)summarizes the characteristics of the walls and windows and shows whether they comply. The building "PASSES" if the cooling load in the proposed design is no greater than in the reference design. Otherwise it "FAILS". In the event of failure, return to the Input screen to try again. It may be helpful to compare the RSHG (relative solar heat gain) for the proposed and reference designs. It may be possible to identify the orientation which is the worst offender. In addition, it can be useful to check the cooling loads for each orientation to find out where the problem lies.

Main-Menu

Returns to the main menu.

Roof

Includes *Input*, *Results* and *Main-Menu* for roof and skylight compliance.

Inputs

The roof calculations are independent of the wall and windows calculation. This part of the program checks compliance of the roof and skylights with the prescriptive requirements of the code. For the roof, the spreadsheet calculates the average Roof Heat Gain Factor (RHGF), which must be less than 0.05. For skylights, the user enters the skylight area and shading coefficient, and the spreadsheet checks that the effective aperture is less than 0.025.

These calculations are not as complex as the system performance calculations for walls and windows; therefore, hand calculations are also possible. However, some will find the program useful as a reminder of the requirements and as a method for documenting the calculations.

The user may enter as many as four roof surfaces. Portions of the roof may differ in their color, level of insulation or presence of a radiant barrier. The roof and skylight inputs are described below. The input screen is shown in Figure C-E.

Opaque Roof Area

Enter the horizontal projection of opaque roof area (excluding skylights) in ft^2 or m^2 for each unique roof surface.

U-Value

Enter the U-value of each opaque roof construction ($Btu/h \cdot ft^2 \cdot °F$). Typical values range from 0.05 to 2.0. See the Glossary for assistance in calculating the U-value.

Absorptivity

Enter the absorptivity of the roof's exterior surface. May be a number between 0 and 1. Typical values range from 0.3 for glazed white surfaces to 0.9 for dark surfaces. See the glossary to Chapter 3 for a list of *absorptivity* for common roofing materials.

Radiant Barrier? Y/N

If the roof construction includes a radiant barrier then enter "y", otherwise enter "n". The installation of the radiant barrier must comply with the guidelines described in the Chapter 3 glossary to receive credit.

Skylight Area

Enter the area in ft^2 or m^2 for each type of skylight (must use same units as for opaque roof area).

Shading Coefficient

Enter the shading coefficient (SC) of each type of skylight. SC ranges from 0 to 1.0. See the manufacturer's literature to determine SC.

Results

The results screen (Figure C-F) tells the user whether the roof "PASSES" or "FAILS" the prescriptive requirements. It also lists the total area of the roof and skylights. If the roof fails to comply then it means the RHGF or the Effective Aperture is too large. These terms are described below as well as in the glossary to Chapter 3.

RHGF

Roof Heat Gain Factor for the opaque portion of the roof is calculated by the program. RHGF is equal to the product of U-value, Absorptivity and the radiant barrier credit. The area-weighted average RHGF for the total opaque roof area must be no greater than 0.05 for compliance.

Effective Aperture

Skylight effective aperture is calculated by the spreadsheet and must be less than 0.025 for compliance. For low-rise residential buildings in a heating climate, the maximum effective aperture is 0.0375. Effective aperture is equal to the fraction of total roof area covered by skylights multiplied by the skylight shading coefficient.

Main-Menu Returns to the main menu.

Output

Creates a text file containing the input data and compliance results. The file may be printed later using the DOS "PRINT" command or a word processing program. The file will be saved with a *.PRN extension. For example, if the user enters the name DOGHOUSE, then the file will be saved as DOGHOUSE.PRN.

Color

The user may choose to view the program in color mode, black & white mode or monochrome mode. At the prompt press *C*, *B* or *M*.

Quit

Leaves the program.

Things to Watch Out For

It is possible to do things which crash the program. If it happens, there are a few things the user can try. First, just try hitting the "Enter" key; it may bring back the main menu without the loss of any inputs. The most common problems are related to opening, saving and printing files. Be sure to pay attention to the questions asked by the program when performing these operations, and avoid hitting the "Esc" key when prompted to enter a file name.

Figure C-B ENV1 Project Input Screen

```
PROJECT INPUT

                                 ----------------------------------------
Project Name:                    | Office example                       |
Date:                            | Nov. 23, 1992                        |
Location (1-4):                  |       4                              |
Low-Rise Res.? (Y/N):            |       n                              |
Air-Cond.? (Y/N):                |       y                              |
Heating Clim.? (Y/N):            |       n                              |
                                 ----------------------------------------

For Location
  1 = Barber's Point
  2 = Hilo
  3 = Honolulu
  4 = Lihue

                 Press ESC or ENTER to return to menu
```

Figure C-C ENV1 Walls Input Screen

```
WALLS INPUT
                                  Wall Surfaces
                    1      2      3      4      5      6      7      8
              ---------------------------------------------------------
Orientation  |      N      n      e      E      s      s      w      w |
Wall Area    |   3000   1300   2000    800   3000   1300   2000    800 |
Glazing Area |    720   1170    480    720    720   1170    480    720 |
 SC          |    0.5   0.72    0.5   0.72    0.5   0.72    0.5   0.72 |
 VLT         |   0.25    0.5   0.25    0.5   0.25    0.5   0.25    0.5 |
 PF          |      0      1      0      1      0      1      0      1 |
 Shade OH,SF,N|     n     oh      n     OH      N     oh      n     oh |
Wall Type M,O |     m      o      m      o      m      o      m      o |
 Uow         |   0.13   0.13   0.13   0.13   0.13   0.13   0.13   0.13 |
 Ins position |     2      2      2      2      2      2      2      2 |
 HC          |      1      1      1      1      1      1      1      1 |
 Shaded? Y,N |      n      y      n      y      n      y      n      y |
 Air-Con? Y,N |     n      n      n      n      n      n      n      n |
              ---------------------------------------------------------

                 Press ESC or ENTER to view results
```

Figure C-D ENV1 Walls Results Screen

```
Input Results Main-Menu
Enter wall and window data

 WALLS RESULTS           Proposed Bldg.                Reference Bldg.

                    North   East  South   West           North  E/W/S
  Wall Area          4300   2800   4300   2800    |        --     --
  Window Area        1890   1200   1890   1200    |        --     --
  WWR                0.44   0.43   0.44   0.43    |      0.44   0.43
  RSHG               0.49   0.37   0.37   0.37    |      0.66   0.32
  Average SC         0.64   0.63   0.64   0.63    |        --     --
  Average Uow        0.13   0.13   0.13   0.13    |      0.15   0.15

                         Cooling Load

                    North   East  South   West           Total
  Proposed         20.993 16.160 25.840 15.164           78.16
  Reference        23.989 15.378 24.776 14.328           78.47

                 ************************************
                 *   PASSES, Proposed < Reference   *
                 ************************************
```

Figure C-E ENV1 Roof Input Screen

```
 ROOF INPUT
                                        Roof Surfaces
                                  1       2       3       4
                               ----------------------------
 Opaque Roof Area             |  10000                     |
 Roof U-Value                 |   0.07                     |
 Absorptance                  |    0.7                     |
 Radiant Barrier?, Y/N        |      n                     |
                               ----------------------------

                                       Skylight Types
                                  1       2       3       4
                               ----------------------------
 Skylight Area                |    288                     |
 Shading Coeff.               |    0.7                     |
                               ----------------------------


                   Press ESC or ENTER to view results
```

Figure C-F ENV1 Roof Results Screen

```
Input Results Main-Menu
Enter roof and skylight data

 ROOF RESULTS

              Opaque Roof Area =      10000
              Skylight Area =           288
              Total Roof Area =       10288


              Roof Heat Gain Factor (RHGF) =        0.049

              ************************
              * PASSES, RHGF < 0.05  *
              ************************

              Skylight Effective Aperture =         0.020

              ************************
              * PASSES, EA < 0.025   *
              ************************
```

Appendix D Weather Data

This Appendix contains weather data for Barber's Point, Hilo, Honolulu, and Lihue. These tables are summaries of hourly weather data, and they are provided here for general reference. The actual hourly data should be used for the Energy Cost Budget Method described in Chapter 6.

A good reference for weather data is *Climatic Data for Region X: Arizona, California, Hawaii, Nevada*, produced by the Golden Gate and Southern California chapters of the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

BARBERS POINT, HI   MONTHLY WEATHER DATA SUMMARY   DOE-2.1

LATITUDE = 21.30   LONGITUDE = 158.10   TIME ZONE =

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
AVG. TEMP. (F) (DRYBULB)	71.7	71.2	72.1	73.9	75.3	77.3	77.7	78.5	78.1	77.2
AVG. TEMP. (F) (WETBULB)	66.8	64.9	66.0	67.3	67.9	69.9	70.3	71.0	70.9	70.2
AVG. DAILY MAX. TEMP.	78.8	78.0	78.7	80.2	81.3	83.2	84.2	84.5	84.1	83.9
AVG. DAILY MIN. TEMP.	63.5	65.0	66.5	68.2	70.1	71.6	72.4	73.2	73.0	71.4
HEATING DEG. DAYS (BASE 65)	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 60)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. DAYS (BASE 80)	0.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0	0.5	0.5
(BASE 75)	6.5	0.5	0.0	16.0	35.0	72.5	102.5	119.0	106.5	86.5
(BASE 70)	65.5	50.0	80.0	126.5	177.0	222.5	257.0	274.0	256.5	238.0
(BASE 65)	193.0	181.5	234.5	276.5	332.0	372.5	412.0	429.0	406.5	393.0
HEATING DEG. HRS./24 (BASE 65)	20.5	4.8	1.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 60)	5.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. HRS./24 (BASE 80)	1.3	0.4	0.1	4.8	5.8	17.6	26.3	32.6	27.7	27.1
(BASE 75)	27.8	17.1	23.8	42.9	56.9	89.4	100.0	116.8	101.2	95.7
(BASE 70)	106.0	76.7	92.2	130.1	168.7	219.2	239.3	263.0	241.5	223.0
(BASE 65)	226.8	179.5	222.5	267.0	320.1	369.0	394.3	418.0	391.5	377.4
MAXIMUM TEMP.	83	82	81	84	91	85	87	86	86	87
MINIMUM TEMP.	52	59	62	64	66	68	70	70	70	68
NO. DAYS MAX. 90 AND ABOVE	0	0	0	0	1	0	0	0	0	0
NO. DAYS MAX. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 0 AND BELOW	0	0	0	0	0	0	0	0	0	0
AVG. WIND SPEED (MPH)	8.7	9.7	10.9	9.9	8.7	7.9	8.3	8.1	7.3	6.5
AVG. WIND SPEED (DAY)	10.4	12.2	12.9	11.5	10.7	10.0	10.4	10.6	9.8	8.8
AVG. WIND SPEED (NIGHT)	7.5	8.0	9.3	8.4	6.7	5.8	6.2	5.7	5.1	4.7
AVG. TEMP. (DAY)	75.8	74.5	75.5	77.0	78.0	80.0	80.5	81.4	81.1	80.7
AVG. TEMP. (NIGHT)	68.9	69.0	69.5	71.1	72.7	74.5	75.0	75.8	75.4	74.3
AVG. SKY COVER (DAY)	5.2	4.7	5.1	5.2	5.5	5.0	4.8	4.6	4.4	4.9
AVG. REL. HUM. AT 4AM	89.3	81.0	82.2	80.5	77.2	79.5	78.9	80.2	79.8	79.7
10AM	73.3	67.1	65.2	66.3	62.1	63.7	64.8	64.2	64.5	65.3
4PM	67.6	62.0	64.0	61.9	61.1	60.7	62.0	59.7	62.5	61.5
10PM	84.2	76.2	79.4	77.6	74.6	75.1	76.1	73.5	76.1	76.9

BARBERS POINT, HI   MONTHLY WEATHER DATA SUMMARY   DOE-2.1

LATITUDE = 21.30   LONGITUDE = 158.10   TIME ZONE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
AVG. DAILY DIRECT NORMAL SOLAR	1341.0	1439.3	1330.3	1329.4	1435.2	1539.3	1641.0	1730.2	1589.3	1552.4
AVG. DAILY TOTAL HORIZNTL SOLAR	1237.2	1473.5	1714.2	1843.3	1983.3	2027.2	2036.0	1993.9	1813.5	1572.3
MAX. DAILY DIRECT NORMAL SOLAR	2180.0	2141.0	2091.0	2148.0	2022.0	2015.0	2118.0	2236.0	2264.0	2071.0
MAX. DAILY TOTAL HORIZNTL SOLAR	1645.0	1884.0	2073.0	2317.0	2298.0	2283.0	2270.0	2259.0	2236.0	1905.0
MIN. DAILY DIRECT NORMAL SOLAR	199.0	67.0	91.0	37.0	410.0	520.0	540.0	859.0	12.0	9.0
MIN. DAILY TOTAL HORIZNTL SOLAR	788.0	605.0	881.0	628.0	1371.0	1401.0	1362.0	1491.0	458.0	337.0
MAX. HRLY DIRECT NORMAL SOLAR	298.0	279.0	266.0	259.0	241.0	243.0	239.0	255.0	271.0	266.0
MAX. HRLY TOTAL HORIZNTL SOLAR	252.0	275.0	293.0	312.0	305.0	306.0	297.0	306.0	309.0	279.0
AVG. MAX. HRLY DIRECT NORML SOLAR	235.9	220.2	200.5	189.5	191.8	199.9	202.8	218.2	217.8	221.2
AVG. MAX. HRLY TOTAL HRZNTL SOLAR	204.3	226.9	249.9	261.6	270.0	264.0	267.1	271.3	257.3	232.7
AVG. DAILY TOTAL VERTICAL SOLAR										
AZIMUTH										
N	306.7	380.5	504.5	596.2	752.6	851.9	780.8	594.7	476.5	385.0
E	681.3	832.3	1004.0	1095.1	1158.7	1155.8	1169.2	1141.6	1041.4	887.6
S	1304.9	1288.6	1121.3	858.5	687.4	619.3	605.1	704.7	986.1	1216.9
W	657.9	826.2	972.9	1038.2	1110.4	1139.9	1117.7	1087.2	990.6	862.4
MAX. DAILY TOTAL VERTICAL SOLAR										
AZIMUTH										
N	384.9	487.0	591.4	693.8	836.7	938.3	888.2	687.5	568.9	501.5
E	851.0	1024.8	1177.1	1270.7	1291.5	1266.9	1256.0	1266.5	1193.3	1068.8
S	1624.4	1549.6	1345.4	1031.7	783.6	690.0	664.7	842.3	1183.1	1447.6
W	853.1	992.1	1168.4	1218.1	1231.4	1273.1	1234.7	1224.4	1164.7	993.6
MAX. HRLY TOTAL VERTICAL SOLAR										
AZIMUTH										
N	58.7	72.8	75.9	86.0	87.8	91.0	87.9	70.4	72.9	68.6
E	203.9	215.3	228.5	231.6	224.3	224.6	222.1	230.1	231.7	214.9
S	238.7	213.6	184.9	142.0	104.7	92.0	87.2	116.7	165.2	198.6
W	198.9	210.2	224.6	226.3	216.3	218.2	216.0	225.7	222.7	205.3

BARBERS POINT, HI MONTHLY WEATHER DATA SUMMARY DOE-2.1

DESIGN TEMPERATURES

PER CENT	SUMMER T(DRY)	SUMMER T(WET)	WINTER T(DRY)
1.0	85	75	57
2.5	85	75	61
5.0	84	74	

MONTHLY AVERAGE TEMPERATURES AS A FUNCTION OF HOUR OF THE DAY

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	67.5	68.4	68.7	70.4	72.0	73.8	74.1	75.0	74.9	73.5	72.9	70.3
1	67.5	67.8	68.6	70.1	71.8	73.5	73.8	74.6	74.6	73.3	72.9	69.9
2	67.4	67.4	68.0	69.7	71.5	73.0	73.7	74.4	74.2	72.8	72.4	69.6
3	67.1	66.9	67.9	69.5	71.4	72.7	73.5	74.1	74.1	72.6	72.0	69.3
4	66.9	66.3	67.5	69.0	71.1	72.5	73.0	74.0	73.9	72.3	71.9	69.3
5	66.7	66.4	67.5	68.8	70.9	72.4	73.1	73.6	73.5	72.3	72.1	69.2
6	66.4	66.5	67.2	69.4	71.5	73.9	73.5	74.6	73.9	72.4	72.1	69.0
7	67.4	67.5	69.1	72.5	74.7	76.8	76.6	77.4	76.9	75.3	73.7	69.9
8	72.2	70.8	73.0	75.1	77.0	78.8	78.9	79.3	78.9	78.0	76.2	72.9
9	75.1	73.7	75.1	77.0	78.6	80.2	80.3	81.1	81.0	80.6	77.8	75.7
10	77.0	75.5	76.4	77.9	79.5	80.9	81.9	82.3	82.2	82.2	79.3	77.6
11	77.6	76.5	77.5	78.6	79.7	81.6	81.8	83.2	83.2	82.5	79.9	78.5
12	78.0	76.6	77.8	79.2	79.9	82.3	82.7	83.5	83.5	82.7	80.5	79.1
13	78.0	77.1	78.0	79.3	79.9	82.4	82.9	83.4	83.1	83.0	80.4	78.9
14	77.9	76.3	77.8	79.3	80.0	82.0	83.1	83.7	82.8	83.1	79.6	78.7
15	77.1	76.0	77.1	78.9	79.5	81.7	82.2	83.1	82.5	82.5	78.8	78.4
16	76.4	75.2	76.1	77.7	78.4	81.0	81.5	82.4	81.6	81.3	77.8	77.3
17	74.4	73.8	74.9	76.3	77.4	80.3	80.7	81.1	80.2	79.5	76.5	75.4
18	72.6	72.1	72.8	74.9	76.5	78.5	79.5	79.6	78.9	77.6	75.2	73.7
19	71.1	71.1	71.2	73.3	74.5	77.1	77.5	78.1	77.0	76.4	74.7	72.4
20	70.0	70.5	70.5	72.5	73.6	75.7	76.2	77.0	76.1	75.4	74.0	71.4
21	69.3	69.8	69.9	71.8	73.1	75.1	75.4	76.5	75.6	74.8	73.7	71.2
22	68.4	69.0	69.5	71.3	73.0	74.7	74.7	75.9	75.5	74.3	73.3	70.5
23	67.8	68.7	69.2	70.8	72.6	74.3	74.5	75.6	75.1	73.9	72.9	70.1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GROUND TEMPERATURES	533.8	533.2	533.2	533.5	534.5	535.6	536.5	537.1	537.1	536.6	535.8	534.7
CLEARNESS NUMBERS	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98

HILO, HI MONTHLY WEATHER DATA SUMMARY DOE-2.1

LATITUDE = 19.70 LONGITUDE = 155.10 TIME ZONE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
AVG. TEMP. (F) (DRYBULB)	71.0	69.6	71.4	71.5	73.0	73.9	74.6	75.0	74.8	74.5
AVG. TEMP. (F) (WETBULB)	64.8	63.9	65.7	66.9	67.7	68.8	69.9	71.2	70.2	69.7
AVG. DAILY MAX. TEMP.	78.2	77.5	77.7	77.8	80.4	81.4	81.4	80.9	81.8	81.8
AVG. DAILY MIN. TEMP.	65.0	62.8	65.9	66.3	66.4	67.6	68.4	69.9	68.8	68.2
HEATING DEG. DAYS (BASE 65)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 60)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. DAYS (BASE 80)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 75)	2.0	0.0	1.0	0.0	0.5	4.5	14.5	20.0	23.0	12.5
(BASE 70)	59.5	34.0	60.5	64.5	105.5	134.5	151.5	168.0	158.5	155.5
(BASE 65)	204.5	145.0	211.0	212.5	260.5	284.5	306.5	323.0	308.5	310.5
HEATING DEG. HRS./24 (BASE 65)	8.6	11.2	1.0	1.3	0.8	0.0	0.0	0.0	0.0	0.0
(BASE 60)	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. HRS./24 (BASE 80)	1.8	1.9	0.5	0.1	4.0	4.3	7.3	4.7	10.8	8.3
(BASE 75)	17.8	15.8	19.4	15.0	44.4	47.0	56.0	52.9	58.8	57.5
(BASE 70)	78.1	57.0	78.7	73.5	118.4	128.2	151.0	157.2	149.2	146.5
(BASE 65)	193.8	141.0	198.5	197.3	248.1	265.5	298.6	309.9	294.8	293.2
MAXIMUM TEMP.	84	86	82	82	83	84	84	84	86	84
MINIMUM TEMP.	59	56	62	62	63	65	65	68	67	65
NO. DAYS MAX. 90 AND ABOVE	0	0	0	0	0	0	0	0	0	0
NO. DAYS MAX. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 0 AND BELOW	0	0	0	0	0	0	0	0	0	0
AVG. WIND SPEED (MPH)	7.0	8.9	8.7	6.7	8.3	8.8	6.1	6.5	6.1	8.1
AVG. WIND SPEED (DAY)	8.7	10.7	10.5	7.8	9.4	10.2	7.5	7.5	7.2	9.1
AVG. WIND SPEED (NIGHT)	5.8	7.5	7.2	5.6	7.1	7.3	4.7	5.5	5.1	7.2
AVG. TEMP. (DAY)	74.6	73.4	74.6	74.4	76.5	77.0	78.0	78.0	78.5	78.1
AVG. TEMP. (NIGHT)	68.4	66.9	68.7	68.8	69.3	70.4	71.2	72.1	71.4	71.2
AVG. SKY COVER (DAY)	6.2	6.6	6.8	7.4	6.7	7.1	6.3	6.9	6.2	6.9
AVG. REL. HUM. AT 4AM	77.8	79.5	85.1	86.1	88.1	88.1	86.4	91.8	87.4	89.2
10AM	65.6	68.3	67.9	74.9	71.5	70.7	72.8	79.6	72.3	71.5
4PM	68.0	64.2	64.8	72.7	65.5	65.1	71.9	75.1	73.9	69.2
10PM	78.8	83.2	82.8	85.0	86.7	87.9	87.4	89.6	86.7	88.0

HILO, HI MONTHLY WEATHER DATA SUMMARY DOE-2.1

LATITUDE = 19.70 LONGITUDE = 155.10 TIME ZONE =

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
AVG. DAILY DIRECT NORMAL SOLAR	1043.2	1034.8	862.4	700.2	1004.5	1008.0	1174.4	1059.0	1125.4	1044.8
AVG. DAILY TOTAL HORIZNTL SOLAR	1092.7	1244.3	1448.9	1443.0	1652.4	1656.9	1686.4	1590.4	1539.5	1334.7
MAX. DAILY DIRECT NORMAL SOLAR	2170.0	2034.0	2038.0	1773.0	2273.0	2154.0	2229.0	1941.0	2109.0	2095.0
MAX. DAILY TOTAL HORIZNTL SOLAR	1573.0	1791.0	2058.0	2119.0	2403.0	2344.0	2341.0	2146.0	2136.0	1854.0
MIN. DAILY DIRECT NORMAL SOLAR	14.0	11.0	9.0	44.0	0.0	83.0	114.0	89.0	10.0	54.0
MIN. DAILY TOTAL HORIZNTL SOLAR	328.0	382.0	418.0	639.0	471.0	744.0	709.0	746.0	424.0	487.0
MAX. HRLY DIRECT NORMAL SOLAR	298.0	373.0	270.0	240.0	258.0	249.0	272.0	238.0	267.0	286.0
MAX. HRLY TOTAL HORIZNTL SOLAR	246.0	333.0	302.0	297.0	313.0	307.0	318.0	288.0	310.0	285.0
AVG. MAX. HRLY DIRECT NORML SOLAR	183.9	212.3	146.7	123.4	164.0	171.3	191.7	163.5	194.5	195.8
AVG. MAX. HRLY TOTAL HRZNTL SOLAR	180.6	223.1	218.9	215.2	242.3	245.5	254.4	228.4	243.5	223.7

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
AVG. DAILY TOTAL VERTICAL SOLAR										
AZIMUTH										
N	304.4	361.8	505.5	599.0	710.7	778.0	719.8	590.7	468.1	397.0
E	642.5	655.9	862.6	913.6	980.4	904.1	913.6	897.3	887.1	757.2
S	1114.5	1051.9	961.1	764.5	631.8	579.2	552.6	650.7	847.2	1025.0
W	571.0	750.6	885.5	918.9	984.5	992.3	999.3	979.9	873.0	769.2
MAX. DAILY TOTAL VERTICAL SOLAR										
AZIMUTH										
N	411.7	464.9	606.5	709.9	823.4	891.5	859.2	697.5	544.1	455.6
E	899.9	1000.0	1220.5	1199.9	1286.4	1265.3	1229.2	1156.6	1205.9	1033.7
S	1636.1	1515.4	1333.2	992.2	712.6	665.4	647.8	799.3	1196.5	1406.3
W	826.3	1083.6	1159.9	1256.1	1273.5	1248.6	1219.6	1202.6	1179.4	1033.2
MAX. HRLY TOTAL VERTICAL SOLAR										
AZIMUTH										
N	67.1	68.0	79.7	88.7	93.8	93.9	92.3	78.8	76.4	66.9
E	198.8	221.1	226.7	213.0	235.9	222.8	223.5	204.2	239.1	219.7
S	232.4	262.8	182.0	137.5	99.6	89.8	84.7	109.0	164.2	200.2
W	191.1	257.3	220.7	220.2	237.0	216.4	223.0	222.1	230.3	213.8

HILO, HI MONTHLY WEATHER DATA SUMMARY DOE-2.1

DESIGN TEMPERATURES -------------------------------- SUMMER ---------- WINTER

PER CENT	T(DRY)	T(WET)	T(DRY)
1.0	83	75	60
2.5	83	75	61
5.0	82	74	

MONTHLY AVERAGE TEMPERATURES AS A FUNCTION OF HOUR OF THE DAY

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	67.4	65.6	67.7	67.9	68.2	69.6	70.2	71.1	70.6	70.3	69.7	66.7
1	66.9	65.4	67.3	67.5	67.7	69.1	69.7	70.8	70.1	70.0	69.3	66.5
2	66.6	65.1	66.9	67.4	67.3	68.8	69.6	70.9	70.0	69.6	69.2	66.1
3	66.1	64.9	66.6	67.0	67.2	68.5	69.5	70.7	69.8	69.3	68.9	65.7
4	65.8	64.8	66.3	66.9	66.9	68.4	69.3	70.7	69.6	69.0	68.6	64.9
5	66.4	64.8	67.1	68.3	66.9	68.2	70.4	72.3	70.3	68.8	68.5	65.3
6	66.9	64.8	67.8	69.5	68.6	69.5	73.4	73.9	73.5	69.5	68.7	67.5
7	67.5	66.5	68.7	71.0	72.9	72.4	76.2	75.5	76.6	72.8	71.1	72.8
8	70.7	70.5	71.3	72.7	75.5	75.2	77.2	76.8	77.9	76.8	74.3	75.2
9	73.9	72.6	73.7	74.4	76.3	77.3	78.1	77.9	79.2	78.5	75.8	76.0
10	77.1	74.1	76.3	76.2	77.8	78.2	79.2	79.2	79.8	79.4	76.8	76.8
11	77.1	75.0	76.6	76.5	79.0	78.9	79.6	79.6	80.4	80.3	77.4	77.2
12	77.1	75.7	77.1	76.7	79.4	80.1	80.4	80.2	81.0	81.1	78.4	77.2
13	77.1	76.5	77.5	77.0	79.4	80.4	80.4	80.6	80.6	80.9	78.1	76.6
14	76.1	75.8	76.8	76.2	79.0	79.8	79.9	79.6	79.6	80.4	78.0	75.9
15	75.2	74.9	76.0	75.2	78.5	79.4	79.0	78.7	79.0	79.7	77.3	74.7
16	74.2	73.8	75.3	74.4	77.6	78.7	78.2	77.7	77.4	78.4	76.0	73.2
17	73.1	72.3	73.9	73.1	76.2	77.0	76.3	76.5	76.0	77.0	74.3	71.5
18	71.9	71.0	72.4	71.8	74.2	75.5	75.2	75.0	74.6	75.1	72.9	70.4
19	70.7	69.2	70.9	70.5	72.8	73.8	73.2	73.8	73.1	73.5	71.9	69.7
20	69.9	68.0	70.1	70.1	71.2	72.0	72.4	73.0	72.6	72.5	71.3	69.0
21	69.2	67.2	69.5	69.3	70.4	71.3	71.9	72.4	71.8	72.1	71.1	68.3
22	68.4	66.7	68.7	68.9	69.7	70.2	71.4	71.6	71.4	71.4	70.7	67.6
23	67.9	66.2	68.3	68.5	69.1	70.0	70.6	71.3	71.0	70.7	70.1	67.1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GROUND TEMPERATURES	531.8	531.4	531.3	531.5	532.3	533.1	533.7	534.2	534.2	533.9	533.2	532.5
CLEARNESS NUMBERS	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98

TMY HONOLULU, HI MONTHLY WEATHER DATA SUMMARY DOE-2.1

LATITUDE = 21.20 LONGITUDE = 157.55 TIME ZONE =

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
AVG. TEMP. (F) (DRYBULB)		72.1	71.7	73.8	74.3	76.1	78.0	78.8	78.9	78.9	78.2
AVG. TEMP. (F) (WETBULB)		66.8	63.7	67.3	67.0	67.4	69.3	70.0	70.0	69.7	69.9
AVG. DAILY MAX. TEMP.		78.8	78.1	79.9	80.4	82.1	83.9	85.2	84.7	84.7	84.2
AVG. DAILY MIN. TEMP.		66.2	66.5	67.7	68.7	70.9	73.2	73.7	74.9	74.6	73.0
HEATING DEG. DAYS	(BASE 65)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(BASE 60)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. DAYS	(BASE 80)	0.0	0.0	0.0	0.0	0.0	1.0	13.5	6.0	6.0	14.0
	(BASE 75)	7.5	3.0	19.0	24.5	51.0	107.0	139.0	149.0	140.0	113.0
	(BASE 70)	88.0	67.0	120.0	137.0	201.5	257.0	294.0	304.0	290.0	267.0
	(BASE 65)	233.5	205.5	274.0	286.5	356.5	407.0	449.0	459.0	440.0	422.0
HEATING DEG. HRS./24	(BASE 65)	4.8	2.9	2.3	1.2	0.0	0.0	0.0	0.0	0.0	0.0
	(BASE 60)	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. HRS./24	(BASE 80)	2.1	0.4	4.0	4.5	10.9	24.4	38.8	31.1	31.9	31.5
	(BASE 75)	25.7	18.6	42.9	42.8	67.4	99.6	127.9	122.8	119.1	117.4
	(BASE 70)	98.8	77.3	138.2	138.4	189.5	240.1	274.5	276.4	266.7	254.8
	(BASE 65)	223.9	191.1	275.1	278.8	343.4	389.7	429.2	431.4	416.7	408.7
MAXIMUM TEMP.		85	82	84	85	85	87	88	86	87	88
MINIMUM TEMP.		58	61	60	61	65	68	67	72	70	66
NO. DAYS MAX. 90 AND ABOVE		0	0	0	0	0	0	0	0	0	0
NO. DAYS MAX. 32 AND BELOW		0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 32 AND BELOW		0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 0 AND BELOW		0	0	0	0	0	0	0	0	0	0
AVG. WIND SPEED (MPH)		10.3	11.2	9.7	11.0	14.3	13.8	12.3	14.5	11.3	9.6
AVG. WIND SPEED (DAY)		12.5	13.3	11.4	13.7	16.1	15.6	13.9	16.6	14.2	11.5
AVG. WIND SPEED (NIGHT)		8.9	9.8	8.3	8.5	12.4	12.0	10.8	12.6	8.8	8.1
AVG. TEMP. (DAY)		75.4	74.9	77.0	77.4	78.9	80.7	81.8	81.4	81.9	81.2
AVG. TEMP. (NIGHT)		69.8	69.5	71.3	71.3	73.2	75.2	75.9	76.6	76.2	75.6
AVG. SKY COVER (DAY)		5.2	5.0	5.0	5.3	4.7	5.5	4.4	4.5	4.4	4.8
AVG. REL. HUM. AT	4AM	87.2	74.1	84.6	80.2	74.6	76.4	75.6	72.9	74.1	76.5
	10AM	70.6	61.8	68.6	60.6	58.4	60.6	59.5	59.5	55.4	62.2
	4PM	66.8	56.3	62.4	62.7	56.4	56.3	55.9	56.5	57.9	59.0
	10PM	79.5	68.2	75.2	74.2	69.5	70.6	70.7	69.0	69.3	71.2

TMY HONOLULU, HI MONTHLY WEATHER DATA SUMMARY DOE-2.1

LATITUDE = 21.20 LONGITUDE = 157.55 TIME ZONE =

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	
AVG. DAILY DIRECT NORMAL SOLAR	1217.8	1238.7	1216.6	1274.5	1445.5	1394.7	1618.7	1740.7	1598.8	1472.9	1
AVG. DAILY TOTAL HORIZNTL SOLAR	1170.6	1397.3	1629.5	1801.3	1983.6	1969.0	2025.2	1996.4	1836.4	1521.8	1
MAX. DAILY DIRECT NORMAL SOLAR	2161.0	1919.0	2157.0	2077.0	2152.0	1989.0	2170.0	2268.0	2159.0	2191.0	2
MAX. DAILY TOTAL HORIZNTL SOLAR	1628.0	1804.0	2160.0	2266.0	2348.0	2238.0	2292.0	2283.0	2153.0	1909.0	1
MIN. DAILY DIRECT NORMAL SOLAR	32.0	41.0	41.0	25.0	286.0	657.0	737.0	920.0	202.0	39.0	
MIN. DAILY TOTAL HORIZNTL SOLAR	368.0	568.0	706.0	577.0	1240.0	1510.0	1555.0	1502.0	1083.0	588.0	
MAX. HRLY DIRECT NORMAL SOLAR	300.0	274.0	272.0	269.0	242.0	224.0	248.0	266.0	262.0	282.0	
MAX. HRLY TOTAL HORIZNTL SOLAR	249.0	270.0	303.0	313.0	304.0	290.0	300.0	314.0	298.0	273.0	
AVG. MAX. HRLY DIRECT NORML SOLAR	214.8	197.9	173.7	192.0	193.0	177.9	202.0	222.7	217.9	207.5	
AVG. MAX. HRLY TOTAL HRZNTL SOLAR	194.0	213.4	236.0	257.2	269.3	257.9	266.1	277.7	262.8	224.6	
AVG. DAILY TOTAL VERTICAL SOLAR											
AZIMUTH											
N	305.1	395.2	497.8	593.3	749.8	847.1	783.2	583.0	479.6	385.4	
E	660.5	799.6	955.3	1069.3	1137.7	1107.2	1162.5	1074.7	1024.2	873.8	
S	1227.1	1226.2	1072.4	844.7	681.3	630.3	607.3	699.8	995.6	1191.9	1
W	635.8	803.4	958.4	1035.6	1123.0	1120.2	1119.7	1116.9	1001.7	846.5	
MAX. DAILY TOTAL VERTICAL SOLAR											
AZIMUTH											
N	391.7	515.1	590.3	707.4	856.4	902.4	885.1	663.9	583.0	524.0	
E	916.3	1026.6	1164.6	1261.1	1327.0	1244.4	1274.0	1248.2	1129.9	1071.8	
S	1630.2	1508.2	1396.7	1034.5	807.2	709.0	692.9	838.0	1197.7	1520.9	1
W	843.8	980.4	1182.7	1230.8	1254.3	1265.5	1282.9	1218.0	1150.2	1031.0	
MAX. HRLY TOTAL VERTICAL SOLAR											
AZIMUTH											
N	59.9	71.3	76.0	85.8	93.0	90.8	88.8	73.0	70.1	70.2	
E	214.1	218.9	233.9	230.9	228.1	209.9	222.8	226.3	219.9	222.9	
S	234.8	218.3	191.9	141.1	110.2	89.3	89.2	116.7	165.4	209.2	
W	196.6	200.6	225.3	228.3	220.9	216.6	223.1	224.9	222.9	211.2	

TMY HONOLULU, HI MONTHLY WEATHER DATA SUMMARY DOE-2.1

DESIGN TEMPERATURES -------------------------------- SUMMER ---------- WINTER

PER CENT	SUMMER T(DRY)	SUMMER T(WET)	WINTER T(DRY)
1.0	86	73	61
2.5	85	73	63
5.0	85	72	

MONTHLY AVERAGE TEMPERATURES AS A FUNCTION OF HOUR OF THE DAY

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	68.9	68.6	70.3	70.9	72.6	74.6	75.4	76.3	75.8	75.1	74.1	70.5
1	68.3	68.0	69.6	70.3	72.4	74.3	74.9	76.1	75.6	74.6	73.8	70.4
2	67.6	67.7	69.1	69.9	71.9	74.0	74.5	75.6	75.1	74.2	73.2	70.2
3	67.5	67.2	68.8	69.6	71.5	73.5	74.3	75.5	75.0	73.6	72.8	70.6
4	67.6	66.9	68.2	69.2	71.0	73.3	73.9	75.4	74.9	73.2	72.8	70.3
5	67.2	67.4	69.3	69.9	72.4	74.6	75.3	75.2	75.4	74.3	72.8	70.1
6	67.6	68.1	70.4	73.4	74.0	76.0	76.8	75.6	78.0	75.6	72.9	71.2
7	68.3	68.6	71.5	76.3	75.5	77.3	78.2	77.6	80.4	76.8	74.6	73.7
8	71.7	71.0	73.6	77.7	77.1	78.9	80.0	79.5	81.6	78.9	77.0	75.1
9	74.6	73.5	75.9	78.8	79.0	80.4	81.7	81.4	82.9	80.8	78.8	76.0
10	76.2	75.9	78.0	78.9	80.7	82.0	83.5	82.9	83.5	82.8	79.9	77.3
11	77.2	76.5	78.5	79.0	81.0	82.6	83.9	83.3	83.7	83.2	80.6	77.1
12	78.0	77.2	79.3	79.1	81.3	83.1	84.2	83.9	84.0	83.5	80.9	77.1
13	77.4	77.9	79.9	79.2	81.6	83.7	84.6	84.0	84.0	83.9	80.3	76.6
14	76.9	77.0	79.2	78.3	80.8	82.9	83.7	83.4	82.6	82.9	80.0	75.5
15	77.0	76.2	78.6	77.2	80.1	82.2	83.0	82.5	81.7	81.9	79.5	74.4
16	75.8	75.4	77.9	75.7	79.2	81.4	82.1	81.6	79.9	80.9	78.1	73.0
17	74.1	74.0	76.5	74.2	77.7	79.8	80.4	80.2	78.4	79.7	76.9	72.4
18	72.7	72.7	75.1	73.5	76.2	78.2	78.9	78.4	77.7	78.3	76.2	72.3
19	72.3	71.3	73.7	73.0	74.6	76.7	77.3	77.7	77.5	77.2	75.8	72.0
20	71.4	70.9	73.0	72.5	74.5	76.2	77.1	77.3	76.9	76.8	75.5	71.3
21	71.1	70.3	72.3	72.2	73.8	75.8	76.5	77.2	76.5	76.5	75.3	71.1
22	70.4	69.9	71.6	72.0	73.6	75.3	76.3	77.0	76.3	76.1	74.7	70.8
23	69.7	69.2	71.0	71.2	73.3	75.1	75.8	76.5	76.0	75.6	74.7	70.4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GROUND TEMPERATURES	534.5	533.9	533.9	534.2	535.2	536.3	537.2	537.7	537.8	537.3	536.4	535.4
CLEARNESS NUMBERS	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

LIHUE, HI   MONTHLY WEATHER DATA SUMMARY   DOE-2.1

LATITUDE = 21.90   LONGITUDE = 159.30   TIME ZONE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
AVG. TEMP. (F) (DRYBULB)	70.3	71.2	72.0	73.6	74.8	76.6	77.8	78.1	78.4	77.0
AVG. TEMP. (F) (WETBULB)	65.5	64.4	65.8	67.6	69.3	70.5	71.1	71.2	71.7	71.3
AVG. DAILY MAX. TEMP.	77.6	76.4	76.5	77.8	79.9	81.6	83.2	83.7	83.4	82.0
AVG. DAILY MIN. TEMP.	64.0	66.8	68.3	70.3	70.2	73.2	73.8	74.1	73.8	72.6
HEATING DEG. DAYS (BASE 65)	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 60)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. DAYS (BASE 80)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.5	0.0
(BASE 75)	2.5	2.5	1.5	3.5	24.0	72.0	108.0	120.5	108.5	74.0
(BASE 70)	57.5	52.0	91.0	121.5	156.5	222.0	263.0	275.5	258.5	226.0
(BASE 65)	182.5	184.5	230.0	271.5	311.5	372.0	418.0	430.5	408.5	381.0
HEATING DEG. HRS./24 (BASE 65)	15.8	1.3	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 60)	2.3	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 55)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(BASE 50)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COOLING DEG. HRS./24 (BASE 80)	0.4	0.3	0.0	0.0	2.1	6.0	16.4	19.7	20.7	9.9
(BASE 75)	15.8	11.2	9.3	15.9	43.2	60.2	92.3	101.7	110.3	82.4
(BASE 70)	71.7	63.0	82.0	110.0	155.4	198.8	242.8	252.0	252.5	218.3
(BASE 65)	179.9	174.9	221.2	256.8	304.8	348.8	397.8	407.0	402.3	372.3
MAXIMUM TEMP.	82	82	80	80	83	83	85	86	86	84
MINIMUM TEMP.	57	62	56	66	64	69	70	70	68	67
NO. DAYS MAX. 90 AND ABOVE	0	0	0	0	0	0	0	0	0	0
NO. DAYS MAX. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 32 AND BELOW	0	0	0	0	0	0	0	0	0	0
NO. DAYS MIN. 0 AND BELOW	0	0	0	0	0	0	0	0	0	0
AVG. WIND SPEED (MPH)	9.2	11.2	14.3	14.6	10.2	13.5	14.3	13.0	11.1	11.5
AVG. WIND SPEED (DAY)	10.4	12.3	14.6	15.0	10.7	13.8	14.8	13.4	11.7	12.1
AVG. WIND SPEED (NIGHT)	8.4	10.4	14.1	14.3	9.8	13.2	13.9	12.7	10.5	11.0
AVG. TEMP. (DAY)	74.0	73.8	74.1	75.4	77.1	78.6	80.0	80.4	81.0	79.5
AVG. TEMP. (NIGHT)	67.9	69.5	70.3	72.0	72.6	74.6	75.7	76.1	76.2	74.9
AVG. SKY COVER (DAY)	5.6	5.8	6.4	6.7	5.4	5.8	6.1	5.6	5.3	5.5
AVG. REL. HUM. AT 4AM	87.2	74.6	78.2	80.0	83.6	80.8	79.1	78.0	81.5	81.7
10AM	73.1	67.7	70.3	70.8	73.4	69.7	66.8	67.9	67.3	68.8
4PM	69.8	63.4	67.5	69.7	71.0	69.8	68.2	65.0	69.4	73.5
10PM	84.5	73.2	77.4	77.2	79.1	78.9	76.9	75.9	76.7	82.2

LIHUE, HI MONTHLY WEATHER DATA SUMMARY DOE-2.1

LATITUDE = 21.90 LONGITUDE = 159.30 TIME ZONE =

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
AVG. DAILY DIRECT NORMAL SOLAR	1125.9	1095.1	956.7	917.8	1293.4	1239.8	1308.5	1452.7	1414.1	1369.5
AVG. DAILY TOTAL HORIZNTL SOLAR	1113.7	1297.6	1480.6	1638.8	1880.2	1856.6	1849.4	1824.4	1745.7	1475.7
MAX. DAILY DIRECT NORMAL SOLAR	2164.0	2132.0	1948.0	1866.0	2185.0	1955.0	2049.0	2198.0	2249.0	2139.0
MAX. DAILY TOTAL HORIZNTL SOLAR	1590.0	1726.0	2106.0	2167.0	2363.0	2279.0	2249.0	2243.0	2228.0	1852.0
MIN. DAILY DIRECT NORMAL SOLAR	88.0	9.0	8.0	99.0	205.0	181.0	151.0	233.0	444.0	62.0
MIN. DAILY TOTAL HORIZNTL SOLAR	505.0	355.0	429.0	932.0	1113.0	1036.0	854.0	1038.0	1053.0	554.0
MAX. HRLY DIRECT NORMAL SOLAR	304.0	289.0	264.0	249.0	261.0	255.0	259.0	255.0	268.0	296.0
MAX. HRLY TOTAL HORIZNTL SOLAR	243.0	261.0	300.0	299.0	315.0	311.0	311.0	305.0	305.0	307.0
AVG. MAX. HRLY DIRECT NORML SOLAR	222.6	178.9	159.7	140.7	187.2	186.8	204.4	211.7	227.1	234.5
AVG. MAX. HRLY TOTAL HRZNTL SOLAR	195.1	199.9	220.4	231.4	259.8	255.5	265.3	262.5	264.6	241.7
AVG. DAILY TOTAL VERTICAL SOLAR										
AZIMUTH										
N	297.3	388.3	496.4	624.1	730.5	810.8	730.9	573.1	484.8	382.1
E	609.9	733.9	882.1	989.4	1084.7	1022.4	1038.4	1007.6	970.9	815.6
S	1179.2	1174.2	1022.2	865.4	682.7	629.4	610.1	711.2	974.8	1159.7
W	611.7	786.3	893.9	1034.1	1092.9	1122.2	1040.9	1060.3	970.5	812.8
MAX. DAILY TOTAL VERTICAL SOLAR										
AZIMUTH										
N	383.9	494.0	591.2	746.0	838.2	898.5	840.6	640.7	542.9	457.3
E	858.9	955.5	1141.6	1200.0	1344.1	1239.7	1203.4	1198.3	1160.3	1155.7
S	1662.2	1593.6	1321.2	1025.6	801.8	702.0	665.3	871.8	1104.6	1405.1
W	816.9	936.7	1130.3	1226.2	1359.2	1303.8	1206.7	1222.9	1164.8	1028.7
MAX. HRLY TOTAL VERTICAL SOLAR										
AZIMUTH										
N	58.6	68.8	78.9	85.9	92.0	89.4	86.9	75.3	71.6	65.1
E	201.2	203.9	225.2	217.4	238.9	215.4	216.7	227.1	222.8	237.5
S	242.1	226.8	186.7	142.9	108.3	90.3	88.2	122.2	169.7	215.3
W	196.4	199.4	219.4	224.1	235.1	220.2	216.3	246.4	242.1	217.5

LIHUE, HI MONTHLY WEATHER DATA SUMMARY DOE-2.1

DESIGN TEMPERATURES -------------------------------- SUMMER ---------- WINTER

PER CENT	SUMMER T(DRY)	SUMMER T(WET)	WINTER T(DRY)
1.0	84	75	59
2.5	84	74	62
5.0	83	74	

MONTHLY AVERAGE TEMPERATURES AS A FUNCTION OF HOUR OF THE DAY

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	66.9	68.9	69.9	71.5	72.0	74.3	75.4	75.6	75.9	74.7	72.6	70.2
1	66.7	68.9	69.8	71.4	71.6	74.2	75.2	75.6	75.5	74.5	72.1	70.1
2	66.3	68.6	69.7	71.3	71.4	74.1	75.1	75.3	75.5	74.3	72.1	70.0
3	66.2	68.3	69.4	71.0	70.9	73.8	74.8	75.2	75.0	74.0	71.8	69.8
4	65.8	68.0	69.4	70.9	70.7	73.7	74.8	74.9	74.9	73.8	71.8	69.7
5	65.8	68.4	69.6	71.5	71.8	74.5	74.6	75.0	75.3	73.9	71.8	69.7
6	66.2	68.7	70.3	72.2	73.1	75.2	75.8	75.4	77.6	75.8	71.9	69.6
7	66.9	69.0	70.5	72.8	74.3	76.0	77.6	77.1	79.7	78.4	73.3	69.6
8	69.7	70.8	72.1	73.9	75.6	77.4	79.1	79.2	81.4	79.7	76.0	71.8
9	73.0	72.6	73.6	75.3	77.1	78.7	80.4	80.4	81.7	80.7	77.5	73.9
10	75.2	74.4	75.2	76.4	78.5	80.1	81.3	81.6	82.4	81.1	79.1	76.1
11	76.2	74.9	75.5	76.5	78.7	80.5	81.8	82.1	83.0	81.2	79.4	76.3
12	76.4	75.5	75.9	77.0	79.1	80.7	82.3	82.3	82.7	81.3	79.7	76.6
13	76.4	76.1	76.2	77.1	79.4	81.1	82.2	82.4	82.4	80.5	79.4	76.9
14	75.8	75.4	75.3	76.5	78.6	80.1	81.4	81.6	81.1	79.7	78.4	76.0
15	74.5	74.7	74.5	75.8	77.9	79.1	80.5	81.6	80.5	78.6	77.2	75.4
16	73.8	74.0	73.6	75.2	77.1	78.1	79.5	80.4	78.9	76.9	76.4	74.5
17	72.1	72.8	72.7	74.3	76.1	77.1	78.3	78.9	77.9	76.5	75.4	73.5
18	70.9	71.5	71.8	73.4	75.2	76.1	77.0	77.5	77.4	76.1	74.6	72.6
19	69.8	70.2	70.9	72.5	74.2	75.1	76.7	77.2	77.2	75.7	74.5	71.5
20	68.9	69.8	70.6	72.5	73.8	75.0	76.4	76.9	77.0	75.5	73.9	71.1
21	68.2	69.4	70.3	72.2	73.3	74.8	76.1	76.5	76.7	75.1	73.7	70.9
22	67.8	69.0	70.0	72.1	72.9	74.7	76.0	76.1	76.4	75.0	73.6	70.5
23	67.5	69.0	69.9	72.0	72.6	74.6	75.7	76.1	76.1	74.9	73.2	70.4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GROUND TEMPERATURES	533.3	532.6	532.6	532.9	534.1	535.2	536.3	536.9	537.0	536.4	535.4	534.3
CLEARNESS NUMBERS	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98

Appendix E Default Equipment Performance Curves[1]

General

These "default" equipment profiles are provided both to encourage and aid local jurisdictions to develop default or prescribed profiles for use with the energy cost budget method of compliance (Article 13). Although the Code mandates that the equipment which is modeled in Article 13 comply with the basic requirements of Section 10.3, it does not provide guidance on the modeling of part-load performance to comply with the part-load performance criteria (IPLV). Default profiles provide a level playing field and simulate reasonable performance. To fairly compare a proposed design against a budget model, the same part-load performance curves must be used for the same equipment in both models. The sole exception is when improved part-load performance is an integral part of the proposed design. In these cases, manufacturer's performance data can be used to develop curves for the equipment in the proposed design.

Article 13 does not require that the simulation tool be able to use all of the performance curves. Where the capabilities of the simulation tool are limited, the designer should make a reasonable effort to incorporate those aspects of the default curves that the program is capable of modeling.

The majority of these profiles are from DOE2.1D. The sole exceptions are the small single compressor part-load performance curve (Table E-H) and the fan part-load performance curves (Table E-A). These additional curves were developed by Steve Taylor for the California Energy Commission as default curves for compliance with California's 1988 and 1992 Nonresidential Building Energy Efficiency Standards.

There are primarily two families of curves provided: those that modify efficiency at part load, and those that modify capacity for changing environmental variables. Note that all performance curves are relative to unit rated capacity or efficiency.

Equipment Profiles

Fan Curves

For variable volume systems, fan input power should be adjusted as a function of fan flow. This relationship is given by the following equation:

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1 This appendix is an excerpt from the *ASHRAE Standard 90.1-1989 User's Manual*, Chapter 13.

(E-A)

$$P_{in}(CFM) = P_{in}(CFM_{max}) \times \left[A + B\frac{CFM}{CFM_{max}} + C\left(\frac{CFM}{CFM_{max}}\right)^2 \right]$$

where

$P_{in}(CFM)$ = input power at the airflow rate, CFM

$P_{in}(CFM_{max})$ = input power at the maximum scheduled airflow rate, CFM_{max}

A,B and C = constants from the Table E-A

The column marked "Minimum Output (% Power)" presents the minimum turndown for the fan as a percent of input power. For the variable speed drive case, the fan can safely be turned down to a minimum of 10% full-load rated input power (corresponding to 20% air movement capacity). Operation at airflows below this point should be simulated with a flat minimum power requirement. This is depicted in Figure E-A.

System Cooling Equipment Curves

There are two families of default curves to be provided for each cooling system: capacity corrections and performance corrections.

In general the available capacity varies with both the entering coil conditions, the percentage rated airflow and (for DX equipment) the condenser conditions. The generic corrections for total and sensible cooling capacity are given by the following:

(E-B)

$$CCAP = CCAP_{rated} \times COOL - CAP - FT \times RATED - CCAP - FCFM$$

(E-C)

$$RATED - CCAP - FCFM = A + B \times \frac{CFM}{CFM_{MAX}} + C \times \left(\frac{CFM}{CFM_{MAX}}\right)^2 + D \times \left(\frac{CFM}{CFM_{MAX}}\right)^3$$

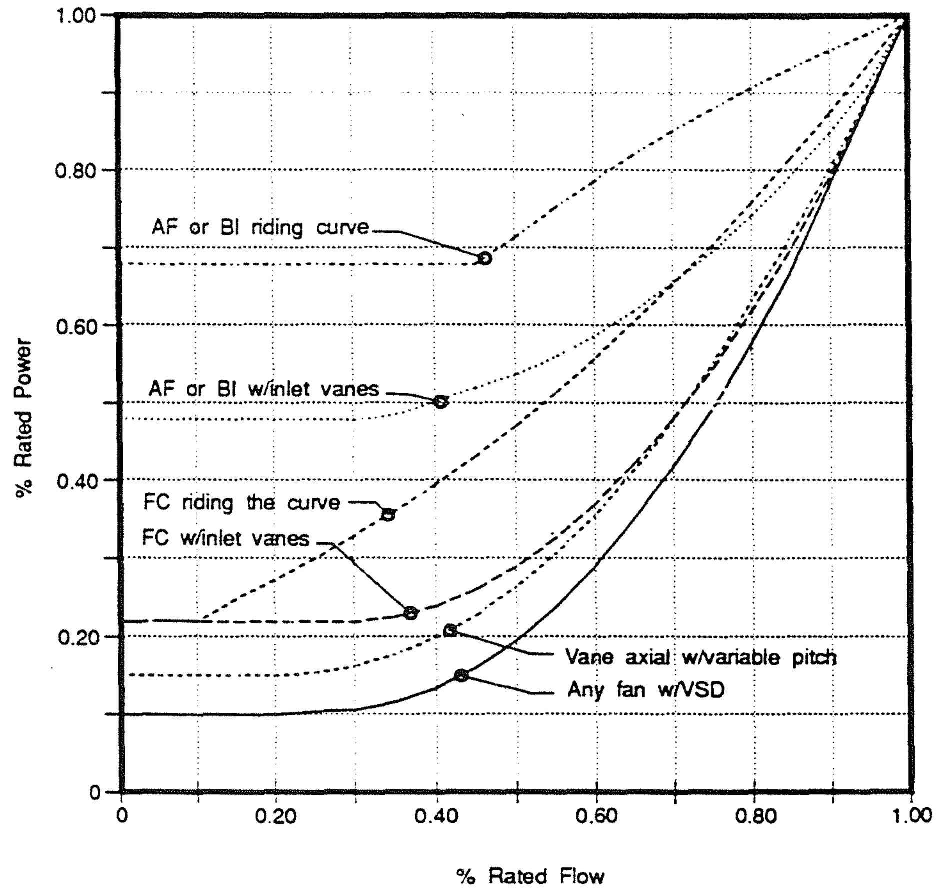
(E-D)

$$SHCAP = SHCAP_{rated} \times COOL - SH - FT \times RATED - SH - FCFM$$

Table E-A Fan Curve Constants

Fan Type - Control Type	A	B	C	Minimum Turndown (%cfm)	Minimum Input (%Power)
Air-foil or backward-inclined - riding the curve	0.227143	1.178929	-0.410714	45%	68%
Air-foil or backward-inclined - inlet vanes	0.584345	-0.579167	0.970238	30%	48%
Forward-curved - riding the curve	0.190667	0.310000	0.500000	10%	22%
Forward-curved - inlet vanes	0.339619	-0.848139	1.495671	20%	22%
Vane-axial - variable pitch blades	0.212048	-0.569286	1.345238	20%	15%
Any - variable speed drive	0.219762	-0.874784	1.652597	10%	10%

Figure E-A Default Fan Curves



(E-E)

$$RATED-SH-FCFM = A + B\frac{CFM}{CFM_{MAX}} + C\left(\frac{CFM}{CFM_{MAX}}\right)^2 + D \times \left(\frac{CFM}{CFM_{MAX}}\right)^3$$

where

CCAP = The total cooling capacity at new condition

$CCAP_{rated}$ = The total cooling capacity at ARI-rated condition

COOL-CAP-FT = An adjustment to the rated total cooling capacity due to environmental variables

RATED-CCAP-FCFM = An adjustment to the rated total cooling capacity due to changes in the airflow rate

SHCAP = sensible cooling capacity at new condition

$SHCAP_{rated}$ = sensible cooling capacity at ARI-rated condition

COOL-SH-FT = adjustment to the rated sensible cooling capacity due to environmental variables

RATED-SH-FCFM = adjustment to the rated sensible cooling capacity due to changes in the airflow rate

CFM = airflow rate at new condition

CFM_{max} = maximum scheduled airflow rate

A, B, C and D = constants from Tables E-B through E-G

The form of the environmental functions COOL-CAP-FT and COOL-SH-FT vary with the type of equipment. Air-cooled DX equipment depends on the outside air dry-bulb and entering coil wet-bulb temperatures, whereas water-source heat pumps depend on the entering water and entering coil wet-bulb temperatures. Cooling are grouped into three categories: chilled-water systems, water-source heat pumps and DX or air-source heat pumps. Each of these are described in detail below.

The cooling performance (efficiency) varies with the entering coil conditions, the percentage rated airflow, the percentage rated load and (for DX equipment) the condenser conditions. The generic corrections for cooling efficiency are given by the following:

(E-F)

$$\mathrm{EIR} = \mathrm{EIR}_{rated} \times \mathrm{COOL-EIR-FT} \times \mathrm{COOL-EIR-FPLR} \times \mathrm{RATED} \\ -\mathrm{EIR-FCFM}$$

(E-G)

$$\mathrm{COOL-EIR-FPLR} = A + B \times \mathrm{PLR} + C \times \mathrm{PLR}^2 + D \times \mathrm{PLR}^3$$

(E-H)

$$\mathrm{RATED-EIR-FCFM} = A + B \times \frac{\mathrm{CFM}}{\mathrm{CFM}_{MAX}} + C\left(\frac{\mathrm{CFM}}{\mathrm{CFM}_{MAX}}\right)^2 \\ + D\left(\frac{\mathrm{CFM}}{\mathrm{CFM}_{MAX}}\right)^3$$

where

EIR = cooling energy input ratio (Btu_{in}/Btu_{out}) at new condition

EIR_{rated} = cooling energy input ratio (Btu_{in}/Btu_{out}) at ARI rated condition

COOL-EIR-FT = adjustment to the rated efficiency due to environmental variables

COOL-EIR-FPLR = adjustment to the rated efficiency due to changes in the coil load

RATED-EIR-FCFM = adjustment to the rated efficiency due to changes in the airflow rate

PLR = ratio of the present load to the rated unit capacity

All other variables previously defined.

Similar to the functions COOL-CAP-FT and COOL-SH-FT, the function COOL-EIR-FT also varies with the type of equipment. All of these functions are three dimensional surfaces which depend on two environmental variables. For example, the COOL-EIR-FT curve for commercial packaged DX equipment (Table E-E) depends on the entering coil wet-bulb (mixed air condition) and the entering condenser dry-bulb temperatures. This surface is depicted in Figure E-B. Note that value of the surface at any condition of entering coil wet-bulb and outside air dry-bulb temperatures is a multiplier times the unit EIR (the inverse of the unit efficiency). A number higher than one represents a decrease in efficiency. The multiplier is unity at the conditions of 67°F entering air wet-bulb and 95° outside air dry-bulb which is the ARI Standard 210 rating conditions for unitary equipment.

Cooling Curves for Central Chilled Water Systems

Chilled water units have adjustment to the total and sensible capacity as afunction of the entering coil dry-bulb and wet-bulb temperatures. There is no adjustment to the cooling efficiency as this is handled at the chiller in the plant model. The curves for these systems take the form of the following:

(E-I)

$$\text{COOL}-\text{CAP}-\text{FT} = A + B \times WB + C \times WB^2 + D \times DB + E \times DB^2 + F \times WB \times DB$$

(E-J)

$$\text{COOL}-\text{SH}-\text{FT} = A + B \times WB + C \times WB^2 + D \times DB + E \times DB^2 + F \times WB \times DB$$

where

DB = entering coil dry-bulb temperature (°F, mixed air condition)
WB = entering coil wet-bulb temperature (°F, mixed air condition)

Separate curves are provided for central air systems which use chilled water (Table E-B), and fan-coil systems (Table E-C).

Figure E-B COOL-EIR-FT for Commercial Packaged DX Unit

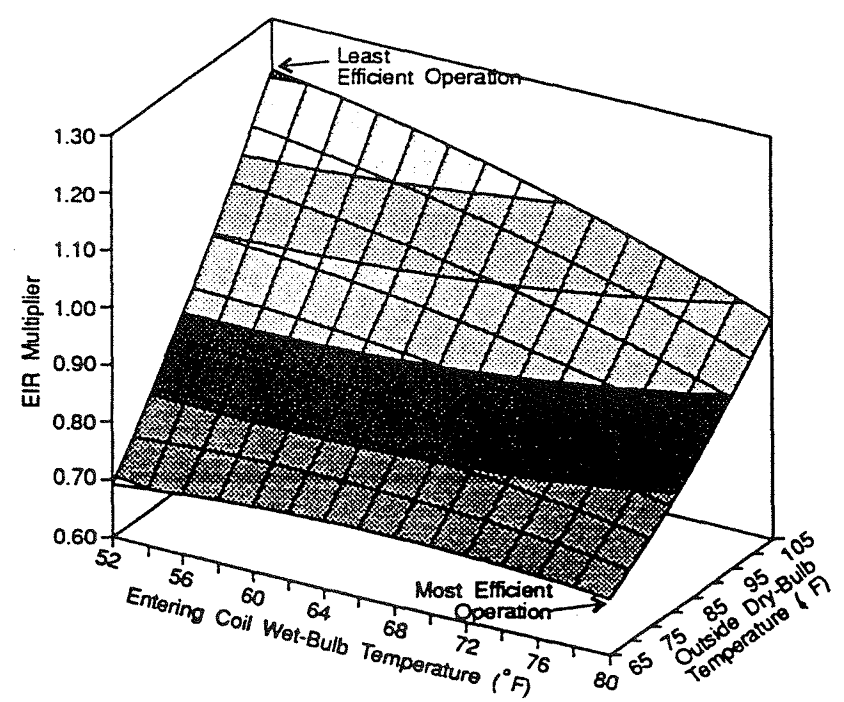


Table E-B Default Coefficients for Central Chilled Water Systems

Curve Name			A	B	C	D	E	F
COOL-CAP-FT	WB	DB	2.58825850	−.23058790	.00383591	.10258116	.00059844	−.00287210
COOL-SH-FT	WB	DB	.89827669	−.13123670	.00196883	.08966396	.00057034	−.00200873
RATED-CCAP-FCFM	CFM-PLR		.18883215	1.09280530	−.28163740			
RATED-SH-FCFM	CFM-PLR		.20164516	.85537158	−.05700167			

Table E-C Default Coefficients for Fan-Coil Systems

Curve Name			A	B	C	D	E	F
COOL-CAP-FT	WB	DB	.50388665	−.08691760	.001684670	.03363036	.00024777	−.00102968
COOL-SH-FT	WB	DB	−1.22805400	−.03209560	.000433810	.05749134	.00013737	−.00056850
RATED-CCAP-FCFM	CFM-PLR		.18273451	1.09902070	−.281755200			
RATED-SH-FCFM	CFM-PLR		.15461794	1.00522590	−.159843830			

Table E-D Default Coefficients for Water-Source Heat Pumps

Curve Name			A	B	C	D	E	F
COOL-CAP-FT	WB	WT	−.27803770	.02483069	−.00000954	−.00327310	.00000703	−.00002720
COOL-EIR-FPLR	PLR		.12500000	.87500000				
COOL-EIR-FT	WB	WT	2.02803850	−.04230910	.00035054	.01496715	.00002438	−.00016396
COOL-SH-FT	WB	WT	1.01813130	.04775910	−.00066600	−.00810620	.00001950	.00005371
HEAT-CAP-FT	DB	WT	.48865341	−.00677740	.00000000	.01408231		
HEAT-EIR-FPLR	PLR		.08565215	.93881371	−.18343610	.15897022		
HEAT-EIR-FT	DB	WT	1.38761020	.00604794	.00000000	−.01158520		
RATED-CCAP-FCFM	CFM-PLR		.93940260	−.30055550	.54955622	−.18840430		
RATED-CEIR-FCFM	CFM-PLR		.99987312	.28009428	−.43560500	.15563756		
RATED-HCAP-FCFM	CFM-PLR		.48381838	.81807753	−.30189590			
RATED-HEIR-FCFM	CFM-PLR		1.46065270	−.79696470	.33631204			
RATED-SH-FCFM	CFM-PLR		−.13002530	2.15830620	−1.60168200	.57340154		

Table E-E Default Coefficients for Commercial Packaged DX or Heat Pump Equipment

Curve Name			A	B	C	D	E	F
COOL-CAP-FT	WB	ODB	.87403018	−.00114160	.00017110	−.00295700	.00001018	−.00005917
COOL-EIR-FPLR	PLR		.20123007	−.03121750	1.95049790	−1.12051040		
COOL-EIR-FT	WB	ODB	−1.06393100	.03065843	−.00012690	.01542130	.00004973	−.00020960
COOL-SH-FT	WB	ODB	4.83529620	−.05753070	.00006155	−.00526830	.00000317	.00003375
HEAT-CAP-FT	ODB		.25367141	.01043512	.00018606	−.00000149		
HEAT-EIR-FPLR	PLR		.08565215	.93881371	−.18343610	.15897022		
HEAT-EIR-FT	ODB		2.46002990	−.06225390	.00088002	−.00000460		
RATED-CCAP-FCFM	CFM-PLR		.47278589	1.24334150	−1.03870550	.32257813		
RATED-CEIR-FCFM	CFM-PLR		1.00794840	.34544129	−.69228910	.33889943		
RATED-SH-FCFM	CFM-PLR		.34465606	.89289891	−.35544980	.11789480		

Cooling Curves for Water-Source Heat Pumps

Water-source heat pump units have adjustment to the total and sensible capacity and cooling efficiency as a function of the entering coil wet-bulb and entering water temperatures. The curves for these systems take the form of the following:

(E-K)

$$\mathrm{COOL-CAP-FT} = A + B \times WB + C \times WB^2 + D \times WT + E \times WT^2 + F \times WB \times WT$$

(E-L)

$$\mathrm{COOL-SH-FT} = A + B \times WB + C \times WB^2 + D \times WT + E \times WT^2 + F \times WB \times WT$$

(E-M)

$$\mathrm{COOL-EIR-FT} = A + B \times WB + C \times WB^2 + D \times WT + E \times WT^2 + F \times WB \times WT$$

where

WT = entering water temperature (°F)

All other variables previously defined.

Cooling Curves for Air-Cooled DX or Heat Pump Equipment

Air-cooled DX or heat pump equipment has adjustment to the total and sensible capacity and cooling efficiency as a function of the entering evaporator wet-bulb and entering condenser dry-bulb temperatures. The curves for these systems take the following form :

(E-N)

$$\mathrm{COOL-CAP-FT} = A + B \times WB + C \times WB^2 + D \times ODB + E \times ODB^2 + F \times WB \times ODB$$

(E-O)

$$\mathrm{COOL-SH-FT} = A + B \times WB + C \times WB^2 + D \times ODB + E \times ODB^2 + F \times WB \times ODB$$

(E-P)

$$COOL-EIR-FT = A + B \times WB + C \times WB^2 + D \times ODB + E \times ODB^2 + F \times WB \times ODB$$

where

ODB = outdoor dry-bulb temperature (°F)

All other variables previously defined.

The coefficients for DX and heat pump equipment are broken into three categories: larger commercial units (Table E-E), packaged terminal air conditioners (Table E-F) and residential units (Table E-G). A fourth table provides the default COOL-EIR-FPLR curve for small, constant speed, single compressor units, either residential or commercial (Table E-H). Where compressors are not provided with unloading capabilities this curve should be substituted.

System Heating Equipment Curves

This section contains default heating curves for the following systems: electric resistance heaters, gas/oil furnaces and heat pumps. In general, heating capacity varies with both environmental conditions and airflow. The generic corrections for heating capacity are given by the following:

(E-Q)

$$HCAP = HCAP_{rated} \times HEAT-CAP-FT \times RATED-HCAP-FCFM$$

(E-R)

$$RATED-HCAP-FCFM = A + B \times \frac{CFM}{CFM_{MAX}} + C \times \left(\frac{CFM}{CFM_{MAX}}\right)^2 + D \times \left(\frac{CFM}{CFM_{MAX}}\right)^3$$

where

HCAP = total cooling capacity at new condition

$HCAP_{rated}$ = total cooling capacity at ARI rated condition

HEAT-CAP-FT = adjustment to the rated total cooling capacity due to environmental variables

RATED-HCAP-FCFM = adjustment to the rated total cooling capacity due to changes in the airflow rate

All other variables previously defined.

Table E-F Default Coefficients for Packaged Terminal Air Conditioners

Curve Name			A	B	C	D	E	F
COOL-CAP-FT	WB	ODB	1.18393450	-.00810870	.00021104	-.00614250	.00000162	-.00000300
COOL-EIR-FPLR	PLR		.12500000	.87500000				
COOL-EIR-FT	WB	ODB	-.65504610	.03889096	-.00019250	.00130464	.00013517	-.00022470
COOL-SH-FT	WB	ODB	6.31127090	-.11299510	.00043336	.00377381	-.00004990	.00006375
HEAT-CAP-FT	ODB		.25367141	.01043512	.00018606	-.00000149		
HEAT-EIR-FPLR	PLR		.08565215	.93881371	-.18343610	.15897022		
HEAT-EIR-FT	ODB		2.46002990	-.06225390	.00088002	-.00000460		
RATED-CCAP-FCFM	CFM-PLR		.80000000	.20000000				
RATED-CEIR-FCFM	CFM-PLR		1.15520000	-.18080000	.02560000			
RATED-HCAP-FCFM	CFM-PLR		.84000000	.15000000				
RATED-HEIR-FCFM	CFM-PLR		1.39240000	-.44680000	.05440000			
RATED-SH-FCFM	CFM-PLR		.60000000	.40000000				

Table E-G Default Coefficients for Residential DX or Heat Pump Units

Curve Name			A	B	C	D	E	F
COOL-CAP-FT	WB	ODB	.60034040	.00228726	-.00001280	.00138975	-.00008060	.00014125
COOL-EIR-FPLR	PLR		.12500000	.87500000				
COOL-EIR-FT	WB	ODB	-.96177870	.04817751	-.00023110	.00324392	.00014876	-.00029520
COOL-SH-FT	WB	ODB	6.52756980	-.12613750	.00056879	.00907575	-.00004830	-.00000875
HEAT-CAP-FT	ODB		.29495686	.01425344	-.00001170	.00000059		
HEAT-EIR-FPLR	PLR		.08565215	.93881371	-.18343610	.15897022		
HEAT-EIR-FT	ODB		2.18554780	-.04947180	.00070417	-.00000401		
RATED-CCAP-FCFM	CFM-PLR		.80000000	.20000000				
RATED-CEIR-FCFM	CFM-PLR		1.15600000	-.18160000	.02560000			
RATED-HCAP-FCFM	CFM-PLR		.84000000	.16000000	.00000000			
RATED-HEIR-FCFM	CFM-PLR		1.38240000	-.43360000	.05120000			
RATED-SH-FCFM	CFM-PLR		.60000000	.40000000				

Table E-H Default Coefficients for Small Single Compressor AC Units and Heat Pumps

Curve Name		A	B	C	D	E	F
COOL-EIR-FPLR	PLR	-.00057143	1.2285714	-.22857143			

Table E-I Default Coefficients for all Fuel or Gas Furnaces

Curve Name		A	B	C	D	E	F
FURNACE-HIR-FPLR	PLR	.01861000	1.0942090	-.11281900			

The form of the environmental function HEAT-CAP-FT varies with the type of equipment. Air-cooled heat pump equipment depends on the outside air dry-bulb and entering coil wet-bulb temperatures, whereas water-source heat pumps depend on the entering water and the entering coil wet-bulb temperatures. These functions are described in detail under discussion of specific heating equipment below.

In general the heating performance (efficiency) varies with the entering coil conditions, the percentage rated airflow, the percentage rated load and (for heat pump equipment) the condenser conditions. The generic corrections for heating efficiency are given by the following:

(E-S)

$$HEIR = HEIR_{rated} \times HEAT - EIR - FT \times HEAT - EIR - FPLR \times RATED$$
$$-HEIR - FCFM$$

(E-T)

$$HEAT - EIR - FPLR = A + B \times PLR + C \times PLR^2 + D \times PLR^3$$

(E-U)

$$RATED - HEIR - FCFM = A + B \times \frac{CFM}{CFM_{MAX}} + C \times \left(\frac{CFM}{CFM_{MAX}}\right)^2$$
$$+D \times \left(\frac{CFM}{CFM_{MAX}}\right)^3$$

where

HEIR = heating energy input ratio (Btu_{in}/Btu_{out}) at new condition

$HEIR_{rated}$ = heating energy input ratio (Btu_{in}/Btu_{out}) at ARI-rated condition

HEAT-EIR-FT = adjustment to the rated efficiency due to environmental variables

HEAT-EIR-FPLR = adjustment to the rated efficiency due to changes in the coil load

RATED-HEIR-FCFM = adjustment to the rated efficiency due to changes in the airflow rate

All other variables previously defined.

Like HEAT-CAP-FT, HEAT-EIR-FT also varies with the type of equipment as described below.

Electric Resistance Heaters

These systems have no adjustments to either capacity or efficiency.

Gas and Oil Furnaces

Fuel-fired heaters do not have adjustments to either their capacity or efficiency due to environmental conditions. They do have an efficiency adjustment due to part-load operation. This FURNACE-HIR-FPLR operates just like the HEAT-EIR-

FPLR previously described in Equation E-T. The coefficients for this curve are given in Table E-I.

Heat Pumps

Both air-source and water-source heat pumps have adjustments to both their capacity and efficiency as described above. These units differ in the environmental variables that are used to vary both the capacity and efficiency. Water-source heat pumps depend on the entering coil dry-bulb and entering water temperatures as follows:

(E-V)

$$HEAT - CAP - FT = A + B \times DB + C \times DB^2 + D \times WT + E \times WT^2 + F \times DB \times WT$$

(E-W)

$$HEAT - EIR - FT = A + B \times DB + C \times DB^2 + D \times WT + E \times WT^2 + F \times DB \times WT$$

The coefficients for the water-source heat pump curves are given in Table E-D.

Air-source heat pumps depend only an the entering dry-bulb temperature for the outdoor coil as follows:

(E-X)

$$HEAT - CAP - FT = A + B \times ODB + C \times ODB^2 + D \times ODB^3$$

(E-Y)

$$HEAT - EIR - FT = A + B \times ODB + C \times ODB^2 + D \times ODB^3$$

The coefficients for these equations are presented in Tables E-E, E-F and E-G.

Plant Cooling Equipment Curves

Central cooling equipment has both capacity and performance corrections. The performance (efficiency) of the equipment is adjusted for part-load and environmental conditions. The environmental conditions are the chilled water supply temperature and the entering condenser water temperature. The capacity of the chillers are also adjusted for changes in the chilled and condenser water temperatures. The general format for these correction curves are as follows:

(E-Z)

$$EIR = EIR_{rated} \times EIR - FT \times EIR - FPLR$$

(E-AA)

$$CAP = CAP_{rated} \times CAP - FT$$

(E-BB)

$$EIR - FT = A + B \times CHWS + C \times CHWS^2 + D \times CWS + E \times CWS^2 + F \times CHWS \times CWS$$

(E-CC)

$$EIR - FPLR = A + B \times PLR + C \times PLR^2 + D \times PLR^3$$

(E-DD)

$$CAP - FT = A + B \times CHWS + C \times CHWS^2 + D \times CWS + E \times CWS^2 + F \times CHWS \times CWS$$

where

EIR = ratio of power input to cooling output (Btu_{in}/Btu_{out})
EIR_{rated} = EIR at ARI-rated conditions
EIR-FT = adjustment for chilled and condenser water temperatures
EIR-PLR = adjustment for part-load conditions
CAP = cooling capacity present conditions
CAP_{rated} = cooling capacity at rated conditions
CAP-FT = adjustment for chilled and condenser water temperatures
CHWS = chilled water supply temperature (°F)
CWS = condenser water supply temperature (°F)
All other variables previously defined.

The coefficients for compression chillers are given in Table E-J. The coefficients in this table are distinguished by compressor type. Separate coefficients are given for hermetic (HERM) and open (OPEN) compressors. Coefficients are also differentiated for centrifugal (CENT) and reciprocating (REC) compressors. Scroll compressors should use the curves for reciprocating compressors and screw compressors should use the curves for centrifugal machines.

Absorption Chillers

Absorption chillers use the same form of capacity and performance curves as compression chillers. For absorption machines the term HIR (heat input ratio) is used in lieu of EIR (energy input ratio), but aside from that the equations are the same. Separate coefficients are given for one-stage (ABSOR1) and two-stage (ABSOR2) machines. These coefficients are in Table E-K.

Plant Heating Equipment Curves

Default curves for central heating equipment are limited to changes in performance at part-load ratios. These are given by the following:

(E-EE)

$$HIR = HIR_{rated} \times HIR - FPLR$$

(E-FF)

$$HIR - FPLR = A + B \times PLR + C \times PLR^2 + D \times PLR^3$$

where

HIR = ratio of heat input to cooling output

HIR_{rated} = HIR at rated conditions

HIR-PLR = adjustment for part-load conditions

Coefficients for hot-water heaters (DHW), heating furnaces and boilers are given in Table E-L.

Table E-J Default Coefficients for Compression Chillers

Curve Name			A	B	C	D	E	F
HERM-CENT-CAP-FT	Tout	Tin	−1.742040	0.029292	−0.000067	0.048054	−0.000291	−0.000106
HERM-CENT-EIR-FPLR	PLR		0.222903	0.313387	0.463710			
HERM-CENT-EIR-FT	Tout	Tin	3.117500	−0.109236	0.001389	0.003750	0.000150	−0.000375
HERM-REC-CAP-FT	Tout	Tin	−4.161461	0.207050	−0.000193	0.004723	−0.000040	−0.000087
HERM-REC-EIR-FPLR	PLR		0.088065	1.137742	−0.225806			
HERM-REC-EIR-FT	Tout	Tin	4.720965	−0.187504	0.002192	0.009029	0.000098	−0.000322
OPEN-CENT-CAP-FT	Tout	Tin	−1.742040	0.029292	−0.000067	0.048054	−0.000291	−0.000106
OPEN-CENT-EIR-FPLR	PLR		0.222903	0.313387	0.463710			
OPEN-CENT-EIR-FT	Tout	Tin	3.117500	−0.109236	0.001389	0.003750	0.000150	−0.000375
OPEN-REC-CAP-FT	Tout	Tin	−4.161461	0.207050	−0.001931	0.004723	−0.000040	−0.000087
OPEN-REC-EIR-FPLR	PLR		0.088065	1.137742	−0.225806			
OPEN-REC-EIR-FT	Tout	Tin	4.720965	−0.187504	0.002192	0.009209	0.000098	−0.000322

Table E-K Default Coefficients for Absorption Chillers

Curve Name			A	B	C	D	E	F
ABSOR1-CAP-FT	Tout	Tin	0.723412	0.079006	−0.000897	−0.025285	−0.000048	0.000276
ABSPR1-HIR-FPLR	PLR		0.098585	0.583850	0.560658	−0.243093	0	0
ABSOR1-HIR-FT	Tout	Tin	0.652273	0	0	−0.000545	0.000055	0
ABSOR2-CAP-FT	Tout	Tin	−0.816039	−0.038707	0.000450	0.071491	−0.000636	0.000312
ABSOR2-HIR-FPLR	PLR		0.013994	1.240449	−0.914833	0.660441	0	0
ABSOR2-HIR-FT	Tout	Tin	1.658750	0	0	−0.029000	0.000250	0

Table E-L Default Coefficients for Heating Equipment

Curve Name		A	B	C	D	E	F
DHW-HIR-FPLR	PLR	0.021826	0.977630	0.000543			
FURNACE-HIR-FPLR	PLR	0.018610	1.094209	−0.112819			
HW-BOILER-HIR-FPLR	PLR	0.082597	0.996764	−0.079361			
STM-BOILER-HIR-FPLR	PLR	0.082597	0.996764	−0.079361			

Appendix F Compliance Checklist

This Appendix contains a compliance checklist. The first side identifies general information about the building and provides space to note which compliance method is used. On the back side is a list of all the code's requirements, with references to specific article numbers. This list is provided as a reference only; not all requirements apply to every building, and the designer should refer to the code or the relevant chapter of this manual for more information.

HAWAII MODEL ENERGY CODE COMPLIANCE CHECKLIST (DRAFT)

BUILDING INFORMATION

Project Name:	Project Date:
Project Address:	
Document Author:	Telephone:

BUILDING TYPE:	☐ High Rise Residential	☐ Low Rise Residential	☐ Commercial	☐ Mixed Use
SPACE CONDITIONING:	☐ Air-conditioned	☐ Naturally Ventilated		☐ Mixed
PHASE OF CONSTRUCTION:	☐ New Construction	☐ Addition	☐ Tenant Improvement	☐ Alteration

CODE ARTICLE	COMPLIANCE METHOD: Meets Basic Requirements	Prescriptive	System Performance	Energy Cost Budget**
5. ELECTRICAL Designer: Telephone: Date of Plans:	☐			
6. LIGHTING Designer: Telephone: Date of Plans:	☐	☐	☐	☐
8. ENVELOPE Designer: Telephone: Date of Plans:	☐	☐	☐	
9. HVAC SYSTEMS Designer: Telephone: Date of Plans:	☐	☐		
10. HVAC EQUIPMENT Designer: Telephone: Date of Plans:	☐			
11. SERVICE WATER HEATING Designer: Telephone: Date of Plans:	☐			
12. ENERGY MANAGEMENT Designer: Telephone: Date of Plans:	☐			

**Energy cost budget method is used for the whole building and is an alternative to the prescriptive or system performance methods for lighting, envelope, and HVAC systems.

BASIC REQUIREMENTS

5. Electrical

- ❑ Electrical power feeders subdivided by usage as required. 5.3(a)(1)
- ❑ Each tenant with a connected load over 100kVA is provided with a separate distribution feeder. 5.3(a)(2)
- ❑ All required separate feeders have either permanent check meters or provisions for attachment of portable meters. 5.3(a)(3)
- ❑ All motors in excess of 1 hp that are expected to operate more than 500 hr per year meet efficiency requirements as required. 5.3(b)
- ❑ The plans or specifications spell out the requirements for operations and maintenance information to be provided to the owner. 5.3(c)

6. Lighting

- ❑ Exterior lighting not for 24-hour use controlled by photocell. 6.3(b)(9)
- ❑ The installed lighting control points equal or exceed the required lighting control points in each and every room. 6.3(b)(2)
- ❑ Shut-off control in each enclosed space. 6.3(b)(1)
- ❑ Controls readily accessible to occupants. 6.3(b)(7)
- ❑ Hotel/motel guest rooms have master switches at the main door to turn off lights and receptacles. 6.3(b)(8)
- ❑ Separate control for luminaires under skylights. 6.3(b)(10)
- ❑ Fluorescent lamp ballasts meet or exceed the ballast efficiency factor (BEF) in Table 6-4. 6.3(d)(1)
- ❑ Fluorescent lamps use multiple lamp ballasts with tandem wiring as required. 6.3(d)(5)
- ❑ Fluorescent lamp ballasts have 90% or greater power factor. 6.3(d)(6)

8. Envelope

- ❑ U-values of opaque envelope components calculated as area-weighted averages, 8.3(a); series and parallel heat flows considered. 8.3(b)
- ❑ Natural ventilation requirements. 8.3(e)(1)
- ❑ Air leakage requirements for air conditioned spaces. 8.3(e)(2)

9. HVAC Systems

- ❑ Load calculations use clg. outside design temps. no greater than ASHRAE's annualized 0.5% values. 9.3(a)(3)
- ❑ Load safety factors do not exceed 10%. Cooling pull-down loads are either calculated or do not exceed 10% of design load. 9.3(a)(8) & 9.3(a)(9)
- ❑ Process loads are served by separate systems from comfort conditioning loads. 9.3(b)
- ❑ Temp. controls provided as required: one for each HVAC system and individual controls for each thermal zone. 9.3(c)(1) & 9.3(c)(2)
- ❑ Thermostats shaded from sun and isolated from heat gain from large equipment. 9.3(c)(3)
- ❑ Thermostatic controls allow cooling setpoints up to 85°F. 9.3(c)(4)
- ❑ Each system that does not need to operate continuously is provided with either automatic time or setback/setup controls. 9.3(d)(1)
- ❑ Isolation controls are provided as required. 9.3(d)(2)
- ❑ Interlock controls on hotel doors to disable cooling. 9.3(d)(3)
- ❑ Humidity controls for comfort are adjustable to 60% min. for dehumidification. 9.3(e)
- ❑ Outdoor air ventilation not to exceed ASHRAE Standard 62-1989 by greater than 10%. 9.3(f)
- ❑ Pipe insulation meets the requirements of Table 9-1 or Eqn. 9-1. Duct insulation meets the requirements of Table 9-2. 9.3(g)(2) & 9.3(g)(3)
- ❑ Plans or specs. spell out the requirements for leakage testing ductwork which operate with static pres. in excess of 3" wc. 9.3(g)(4)
- ❑ Low and medium pressure supply ductwork which is located outside of the conditioned space is sealed in accordance with SMACNA Seal Class C. 9.3(g)(4)
- ❑ Heat recovery for water heating required from large cooling systems. 9.3(h)
- ❑ Complying air and water system balancing procedures are spelled out on the plans or in the specifications. 9.3(i)(2) & 9.3(i)(3)
- ❑ Testing, adjusting and calibration of control systems is spelled out on the plans or in the specifications. 9.3(i)(4)
- ❑ Cooling of unenclosed spaces. 9.3(j)

10. HVAC Equipment

- ❑ Equipment efficiencies meet or exceed requirements of Tables 10-1 through 10-7. 10.3(a)
- ❑ Plans or specifications require that equipment is provided with operation and maintenance manuals and system schematics. 10.3(c)

11. Service Water Heating

- ❑ Equipment eff. meets or exceeds requirements of Table 11-1. 11.3(b)
- ❑ Water heating systems have temperature controls capable of reset down to 90°F (110°F for residential units). 11.3(d)
- ❑ Circulating systems and heated pipes are fully insulated and have automatic controls. 11.3(c)(1) & 11.3(f)
- ❑ For non-circulating systems outlet piping is insulated for 8' from storage tank. 11.3(c)(2)
- ❑ Shower heads have complying flow restriction devices which limit flow to < 2.5 GPM. 11.3(g)
- ❑ Lavatories and sinks have required flow restriction devices and controls. 11.3(h) & 11.3(i)
- ❑ Heated swimming pools use solar or heat pump systems. 11.(j)(2)
- ❑ Pool pumps and electric heaters have automatic time switches. All pool heaters have readily accessible controls. 11.3(j)(1) & 11.3(j)(3)
- ❑ Outlets requiring temperatures above 130°F are served by either booster heaters or dedicated heaters. 11.3(e)

PRESCRIPTIVE REQUIREMENTS

6. Lighting

- ❑ Interior lighting power allowance. 6.4

8. Envelope

- ❑ Opaque roof surfaces. 8.4(a)
- ❑ Opaque wall surfaces. 8.4(b)
- ❑ Vertical glazings. 8.4(c)
- ❑ Horizontal glazings. 8.4(d)

9. HVAC Systems

- ❑ System not oversized. 9.4(a)
- ❑ Constant vol. systems do not reheat, recool or mix air. 9.4(b)
- ❑ Var. vol. systems have minimum stops adjusted as required. 9.4(b)
- ❑ Fan system design criteria. 9.4(c)
- ❑ Pumping system design criteria. 9.4(d)
- ❑ Comfort cond. air systems employ temp. reset controls. 9.4(e)(1)
- ❑ Hydronic systems employ either var. flow or temp. reset controls. 9.4(e)(2)

SYSTEM PERFORMANCE REQUIREMENTS

6. Lighting

- ❑ Interior lighting power allowance. 6.5

8. Envelope

- ❑ Software compliance for walls and windows. 8.5